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A TEXT BOOK OF PHYSIOLOGY.

BY

DR. G. VALENTIN,

PROFESSOR OF PHYSIOLOGY IN THE UNIVERSITY OF BERN.

TRANSLATED AND EDITED FROM THE THIRD GERMAN EDITION,

BY

WILLIAM BRINTON, M.D.,

LICENTIATE OF THE ROYAL COLLEGE OF PHYSICIANS;
PHYSICIAN TO THE ROYAL FREE HOSPITAL;
MEDICAL TUTOR IN KING'S COLLEGE.

WITH UPWARDS OF FIVE HUNDRED ILLUSTRATIONS ON WOOD, COPPER, AND STONE.

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PREFACE.

The work now introduced to the English public is best described as an abridgment, by Professor Valentin, of the last edition of his larger systematic treatise, the "Lehrbuch der Physiologie."

The preface to a translation is no place to enlarge on the merits of the original, or the repute of its Author. The reader probably thinks it enough to be told the main features of the book that follows.

The Author's chief objects have been brevity and completeness. In pursuance of the latter, he has laid great stress on the numerous physico-chemical researches which have done so much for modern Physiology. This has involved a short account of those parts of the physical sciences on which such researches are based.

Hence the advanced student of Physiology may use this book as a convenient summary of many experiments hitherto imperfectly known in this country. While the beginner will certainly find that, in addition to a full though condensed treatment of the first principles of this science, it comprehends so much of various kindred subjects as may either obviate, or what is better, fructify, a reference to the ordinary text-books of each. And in this respect it seems peculiarly adapted to that increasing number of the educated public, who, although unable to devote themselves to an extended course of study, still desire some insight into the natural laws which regulate their own life and welfare.

In order to secure, if possible, a faithful, as well as readable, translation, the original was first rendered into a literal English; the words and phrases of which, where necessary, were afterwards exchanged for simpler or smoother equivalents.

Measurements are everywhere reduced to English feet and inches; and

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weights to the Avoirdupois standard. The calculations necessary for these changes have been made with much care. The number of decimals in the several estimates generally corresponds with those given in the original. In some instances the reader may perhaps think too many have been set down. But by neglecting one or more of the right hand figures, he can always obtain a more simple, though less exact, statement.

Finally, notes have been added by the Editor, in the few instances where he has thought it advisable to modify or explain the meaning of the text.

WILLIAM BRINTON.

King's College, *April*, 1853.

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LIST OF THE WOODCUTS.

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EXPLANATION OF THE PLATES.

(THE FRACTIONS BENEATH THE FIGURES STATE THE NATURAL SIZE OF THE CORRESPONDING OBJECTS).

PLATE I.

FIG.

1. MINUTE crystals of common salt. Deposited from a solution by evaporation on a glass plate.
2. Minute crystals of uric acid. Thrown down by hydrochloric acid from partially evaporated human urine which had been diluted with water.
3. Minute crystals of oxalate of lime. Deposited from the residuum of human urine by standing.
4. Crystals of carbonate of lime. From the otolithe of the green frog.
5. Some of the same crystals, under the polarizing microscope, with parallel Nicol's prisms.
6. The same crystals, with the upper Nicol turned round 60°.
7. The same crystals, with the upper Nicol turned round 90°.
8. Crystalline globules from the urine of the horse under the polarizing microscope, with the Nicol's prisms at right angles.
9. A large starch-granule under the polarizing microscope, with the two Nicol's prisms in parallel planes.
10. The same granule, with the prisms at right angles.
11. The same granule, with the prisms at right angles, and the object plate turned round 45°.
12. The crystalline lens of an adult, as seen under the polarizing apparatus, with Nicol's prisms crossing at right angles. Natural size.
13. Tufts of Haidinger, as seen when looked at through a Nicol's prism against the grey sky. The yellow tuft corresponds to the greater diameter of the prism; and the violet, to the smaller diameter.
    a b. The longer transverse axis of the prism.
    c d. The shorter transverse axis.
14. Posterior half of the retina of an adult. It lies within the sclerotic, and presents the medullary elevation that corresponds to the entry of the optic nerve; together with the vessels which radiate from this point, the central fold, the yellow spot, and the central fossa. Natural size.
15. The central fossa of the retina of another adult. Magnified.
    a. The granular layer of the retina.
    b. The shallow terminal bifurcation of the central fossa.
    c. The radiating rods or papillæ of the *membrana Jacobi* which are seen at the bottom of the fossa.
    d. The deepest part or apex of the central fossa.
16. Gall-stone from the gall-bladder of a girl. It consists of crystals of cholestearine. Magnified from two to three times.
17. Collection of the various substances which are found admixed in the healthy human fæces. All the bodies here represented were found in the same excrement. Here the relics of the various animal and vegetable tissues are only brought close to each other for the sake of economizing space.

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FIG.

a. A starch-granule, exactly in focus, and hence exhibiting its concentric layers.

b c. Two other starch-granules. Their surfaces, being out of focus, have margins which are as dark as those of the oil-drops.

d. Part of the skin of a walnut.

e. A fragment of vegetable epidermis.

f. A reticular vessel from the vegetable food.

g. A striped muscular fibre from the animal food. This has only become more transparent.

h. Other striped fibres, which are beginning to separate into transverse fragments.

i k l. Crystals of ammoniaco-phosphate of magnesia.

m. A cell of the pavement epithelium from the neighbourhood of the rectum, saturated with biliary colouring matter.

n. Large brown particles.

o. Small granules which vary from a greyish-white to a brownish colour, and are met with in large numbers in the fæces.

PLATE II.

18. *Sarcina ventriculi* from the matters vomited by a sick man.
19. *Torula cerevisiæ* from yeast.
20. Crystalline globules from the urine of the horse.
21. Crystalline globules from the sandy matter of the middle choroid plexus of a woman.
    a. Globule with a side process.
    b. Semi-calcified and transparent globule.
22. Lymph from a wounded lymphatic of the upper part of the leg of an adult man. It was taken from the living body; but having been kept for some time in a closed vessel, offered various after-deposits.
    a a. Altered lymph-corpuscles.
    b. Larger granules.
    c. Fine molecular corpuscles in still larger quantity than the preceding.
    d. A crystal of cholestearine.
    e. A crystal of some other substance.
23. Blood- and lymph-corpuscles of the green frog.
    a. The wall of the blood-corpuscle.
    b. Its nucleus.
    c. Lymph-corpuscle of the blood.
24. Blood- and lymph-corpuscles of the human blood.
    a. Blood-corpuscles of blood which had been just taken from the living subject, and was unmixed with any foreign fluid. Seen in surface: and to the right, in edge.
    b. Ordinary lymph-corpuscles of the blood; clear, bright, and colourless.
    c. Somewhat darker (and unusual) lymph-corpuscle.
    d d. Blood-corpuscles aggregated in piles or rouleaux: from the serum of venous blood taken from a person suffering under inflammation of the lungs.
25. Constituents of the sanguineous plug found in the cervix uteri of a woman aged 47 years, who died of pneumonia during menstruation.
    a. Coagulated fibrine.
    b. Swollen blood-corpuscles below the surface.
    c. The same close to the surface.
    d. Small granular globules.
    e. Large dark granular globules.
    f. Large clear granular globules.
26. Substance covering the inner surface of the mucous membrane of the uterus in the same person. This is reddish or red in some points, but is elsewhere transparent and greyish-white.

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FIG.

a. Colourless globules apposed to each other like a pavement, and united by a mucous fluid to form the above transparent substance.

b. A few heaps of partially changed blood-corpuscles, giving rise to the red spots. No coagulated fibrine can here be observed.

27. Fat-cells from the subcutaneous adipose tissue of a woman's thigh.
28. Various forms of pigment-molecules from the human choroid.
29. Hexagonal pigment-cells with transparent nuclei, from the choroid of the frog.
30. Branched pigment-cells from the tissues surrounding an abdominal artery of the same animal.
31. Solid matters of the human saliva.

a b. The oldest shed cells of the pavement-epithelium of the mouth, as seen by shadowed light. *c d.* Salivary corpuscles seen under the light of a lamp.

32. Epithelial cells from the middle epidermal layers of the under surface of the great toe of an adult girl.

a. Cells with structures resembling nuclei.

b c. Separated cells without nuclei.

d. Two epidermal cells which are connected to each other and excavated laterally.

33. Pavement-epithelium of the conjunctiva covering the cornea of a man; seen by shadowed light.

a. Polygonal cells.

b. Their nuclei.

34. Cylindrical cells of epithelium, from the cystic duct of a man.

a. The free surface, which resembles that of a drum.

b. The cylindrical cells, which have granular horny walls.

c. Oval cells.

35. Several cylinders from the same situation. These are arranged like a palisade; being placed obliquely, and somewhat curved below.
36. Ciliated cylinders from the trachea of another man.

a. Larger cylinders, with nuclei above.

b c. Smaller cylinders, with nuclei below.

37. Fresh horny substance from the free extremity of the nail of an adult man's middle finger.
38. A fragment of the same horny substance after repeated boiling in a solution of potash. Here the bright transparent horny cells are seen in their natural position, and many of them retain their nuclei.
39. Fragment of a red hair from the beard of a man.

a. Lines produced by the margin of the cells of the epidermis which clothes the hair.

b. The fibrous streaks of the cortical substance.

c. Continuous medullary substance, which is richer in pigment, and therefore darker.

d. The clearer medullary substance which succeeds its partial interruption.

e. Matters which have collected on the surface of the hair; consisting of shed epithelial cells, fatty substances, and foreign impurities.

PLATE III.

40. Bundles of areolar tissue from between the striped fibres of the trapezius muscle.
41. A portion of the above, treated with acetic acid.

a. Gelatinous basis.

b. Investing filaments.

42. Elastic fibres from the outermost elastic layer of the aorta of the ox.
43. Fenestrated membrane of the same vessel.

a. The membrane.

b. Its apertures.

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FIG.

44. Layer of small reticular fibres from the same artery.

45. Thin transverse section of cartilage from a tracheal ring of an adult.
 a. Granular basis.
 b. Large cartilage-corpuscles.
 c. Small and simple cartilage-corpuscles.
 d. Primary enclosing structures.
 e. Secondary enclosing structures.

46. Thin transverse section of the human femur, slightly magnified.
 a. The basic substance.
 b. Medullary canals cut across.
 c. Lacunæ.

47. Part of the same section more strongly magnified.
 a. The basic substance.
 b. Medullary canal cut across.
 c. Medullary canal descending obliquely.
 d. Osseous laminæ arranged concentrically around the medullary canal.
 e. Lacunæ, with their radiating canaliculi.

48. Thin longitudinal section of the horse's femur.
 a. Medullary canal running longitudinally.
 b. Long lacunæ and their radiating canaliculi.
 c. Round ones which lie more deeply.
 d. Network of the latter.

49. Part of a thin section of a horse's molar tooth.
 a b. True dentine.
 b c. Enamel (which occupies)
 c. The free surface of the tooth.
 d. Tooth-tubes or fibres, taking an arched course here and there. These form enlargements such as are not seen in the healthy human tooth.
 Above *b* the ends of the tooth-fibres branch in the neighbourhood of the enamel. Above *b c* are the fibres of the latter substance. The dark streaks are cracks produced in making the section.

50. A portion of the cement of the same molar tooth.
 a. Its basic substance.
 b. Lacunæ lying deeply.
 c. Others in focus.
 d. Medullary canals, which do not exist in the human teeth.

PLATE IV.

51. Transition of ossifying cartilage into bone. From the upper epiphysis of the tibia of the human embryo at the eighth month.
 a b. Cartilage.
 b c. Adjacent bone.
 At *a b* are seen the cartilage corpuscles partially arranged in rows; and at *b c* the partitions of the young and spongy bone, separated by medullary spaces.

52. Two Meibomian glands from the lower eyelid of a child; seen on a black ground.
 a. Substance of the eyelid.
 b. Vesicular ends of the glands.

53. Gastric glands from a vertical section of the mucous membrane of a healthy man's stomach.
 a. Simple gastric glands.
 b c. The two tubes of a ramified gastric gland.
 d. Openings of the gastric glands on the surface of the mucous membrane.

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FIG.

54. *a.* A striped muscular fibre from the trapezius of a human corpse some time after death. Here no sarcolemma can be seen.
    b. A fibre having a sarcolemma with some nuclei on one side.
55. Outermost layer of the lens. From an adult human eye.
    a. Globules of liquor Morgagni.
    b. A globular mass which appears to have a caudate prolongation.
    c. Deeper fibrous substance.
56. Lenticular fibres from the same lens.
57. Lenticular fibres from the same lens, having fine striæ at right angles to the long axis of the fibres themselves.
58. Bundles of primitive fibres from the radiation of the optic nerve. From the retina represented in Plate I. Fig. 14.
59. Bundle of unstriped muscular fibres from the muscular coat of a man's stomach.
60. Fibre-cells into which these muscular fibres are split up by tearing with fine needles.
    a a. Their nuclei seen indistinctly.
61. A piece of unstriped muscle treated with acetic acid.
    a. The muscular substance which has become transparent.
    b. The now distinct nuclei.
62. Vertical section of the skin of the sole of an adult man's foot, from the surface to the subcutaneous adipose tissue.
    a b. Thickness of the epidermis, the undulating layers of which are indicated by transverse lines.
    b. Region of the Malpighian mucus.
    c. Some of the oldest epidermal scales, partially shed.
    d. Tactile papillæ of the corium.
    e. The same with loops of blood-vessels appearing indistinctly through them.
    f. The remainder of the corium.
    g. Part of the subcutaneous adipose tissue.
    h. Spiral gland taking a tortuous course through the epidermis to open at *i*.
    k. Its straighter transit through the corium.
    l. A second of these, taking wider curves through the corium.
    m. Continuation of the latter.
    n. The place where it divides.
    o p. Its terminal tubes, the coils of which occupy the adipose tissue. Their epithelial structures are partially dissolved by the action of the dilute solution of ammonia by which the whole has been rendered more transparent.
    q r. Proper capsular investment of these terminal tubes.
63. The base of a small hair from the fore-arm of the same man.
    a b. Border of the epidermis.
    c. Horny shaft of the hair.
    d. Horny bulb of the hair.
    e f. Outer and inner root-sheaths.
    g. Canal of the hair-follicle.
    h i. Two sebaceous glands, the ducts of which open into the canal of the hair-follicle.
    k. A third sebaceous gland injured by the section.

PLATE V.

64. A portion of the free extremity of the frog's pancreas, slightly magnified.
    a. Basement membrane of the gland.
    b. Groups of distended terminal vesicles.
65. Portion of an urinary tubule from the kidney of an adult.
    a. Epithelial cells.
    b. Basement membrane from which the cells have been partially removed in the act of preparing the specimen for examination.

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FIG.

66. A Malpighian corpuscle, with its appended urinary tubule. From the kidney of a green frog.
 a. Coil of blood-vessel, in the interior of which we may recognise some blood-corpuscles.
 b c. Its limitary membrane.
 d. The capsule itself.
 e. The adjoining urinary tubule, with its epithelial cells.

67. Proper corpuscles of the cortical substance of the supra-renal capsule,—showing their radiate arrangement. From an adult man.
 a. The side towards the surface.
 b. That towards the interior.
 c. Clear intervening substance.

68. Various primitive nerve-fibres from the sciatic nerve of a newly-killed frog.
 a. A fibre, the contents of which have not yet coagulated, while its margins have become varicose in being prepared for examination.
 b. A large fibre which has almost retained its original cylindrical form.
 c. A small fibre, with notched margins and a distinctly oleaginous content.
 d. A varicose fibre of medium size.

69. A number of primitive nerve fibres from a human corpse somewhat longer after death.
 a. A fibre in the contents of which coagulation is commencing. Its margins are beginning to become varicose.
 b. A fibre (partially concealed), the contents of which have completely coagulated.
 c d. Partial coagulation of the same.
 e. Small fibres, lying deeper, the contents of which have become cloudy here and there.
 f. A fibre in which coagulation is beginning at a part that has been compressed and constricted by the act of preparation.
 g. A fine fibre, which has become varicose at *h;* while its altered contents have protruded at *i.*

70. Large nerve-fibre at its division. From an abdominal nerve of the eel.
 a. The trunk.
 b c. The branches of division.

71. Ganglion-corpuscles with vaginal processes. From the superior thoracic ganglion of the human sympathetic trunk.
 a. Substance of the corpuscle.
 b. Its bright nucleus.
 c. Nucleolus.
 d. Nucleated investment.
 e. Vaginal processes.
 f. Apposed nuclei.
 g. A true nerve-fibre of average diameter running in the neighbourhood.

72. Ganglion-corpuscle with processes of nerve-fibre. From the Gasserian ganglion of a newly-killed eel-pout. (*Gadus lota*).
 a. Corpuscle with its nucleus and nucleolus.
 b c. Its upper and its lower nerve-fibres.
 d. Transparent outline of the membrane which surrounds the ganglion-corpuscle.

73. A similar preparation from the same ganglion; after the animal had been dead many days, and was considerably advanced in putrefaction.
 a. The ganglion-corpuscle, which has become paler and redder.
 b c. The two processes of nerve-fibre; the contents of which have coagulated, and assumed a paler greyish-red aspect.
 d. The upper and constricted point of union, where nervous contents can no longer be recognized.

74. Ganglion-corpuscles from the Gasserian ganglion of a new-born infant.

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FIG.

a. Angular ganglion-corpuscle.
b. Single process of the same.
c. A process which divides into two subordinate branches, *d* and *e*.
f and *g*. Isolated corpuscles devoid of processes.

75. Drops of the liquid contents of primitive nerve-fibres. From the putrid medulla oblongata of the ox.

76. Very large and pale ganglion-corpuscle from the grey substance of the anterior columns. From the inferior cervical region of the spinal cord of a newly-killed ox.
a. The pale substance of the corpuscle.
b. The heaps of granules in its interior.
c. The nucleus.
d. The nucleolus.
e. A simple pale process.
f. A larger process. Here it is impossible to decide whether the primitive fibre *g* really proceeds from it, or only lies on it.

77. Cerebral substance of a new-born male infant. From the upper part of the middle lobe of the brain, at about $\frac{3}{8}$ths of an inch below the surface.
a. Granular substance.
b. Clear cells.
c. Granular nuclei.
d. Similar but less distinct nuclei, apparently free.

78. Elements of human semen.
a. Spermatozoids, exactly in the focus of the microscope.
b. Others outside this point.
c. Smaller seminal globules.
d. Parent-cells of the spermatozoids.

79. Milk of a woman, one day after parturition.
a. Large
b. Medium } milk-corpuscles.
c. Small
d. Colostrum-corpuscles.
e. Scales of epithelium admixed with them.

80. Milk of a woman, ten weeks after parturition.
a. Milk-corpuscles.
b. Colostrum-corpuscles of very small size and number.

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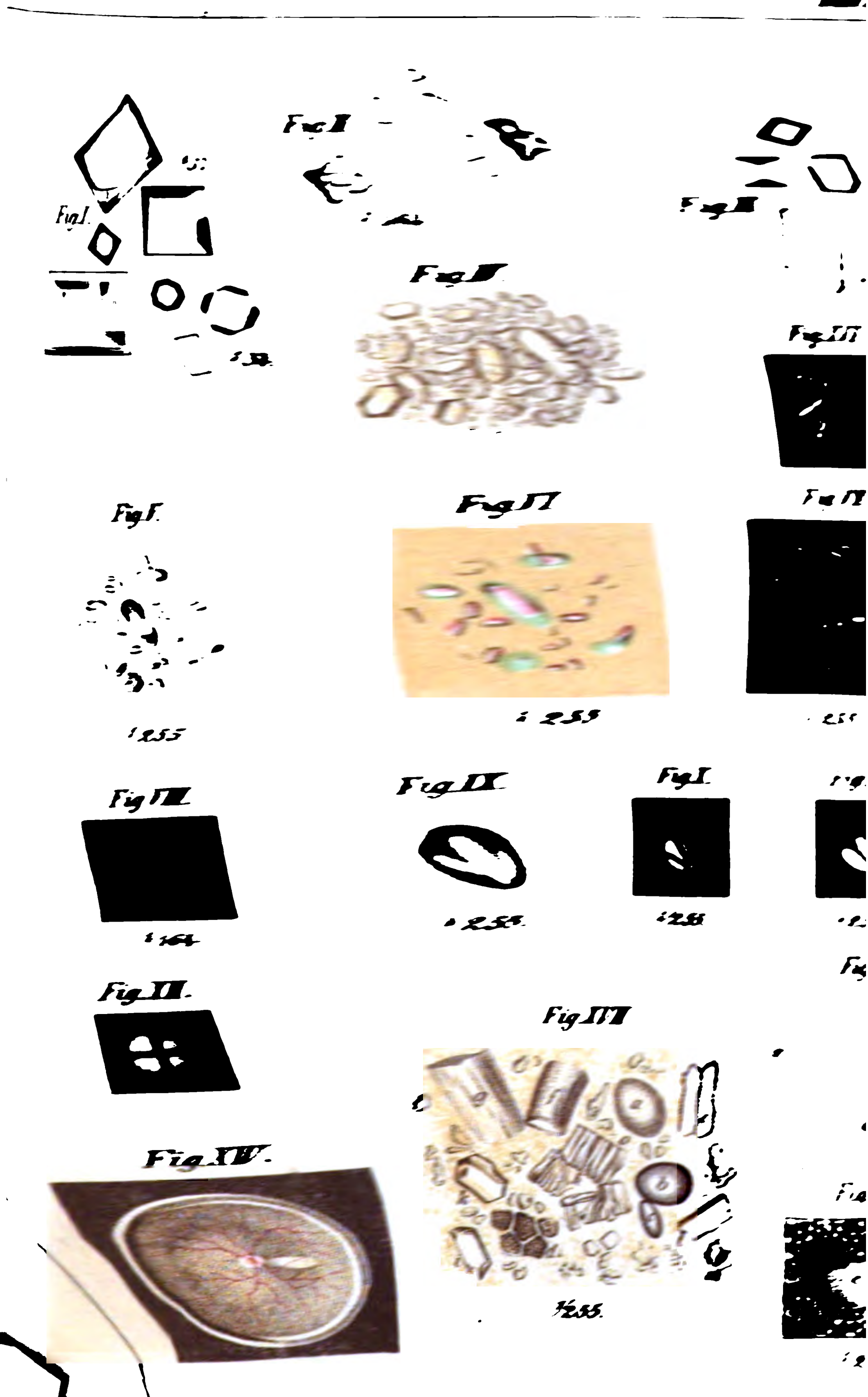

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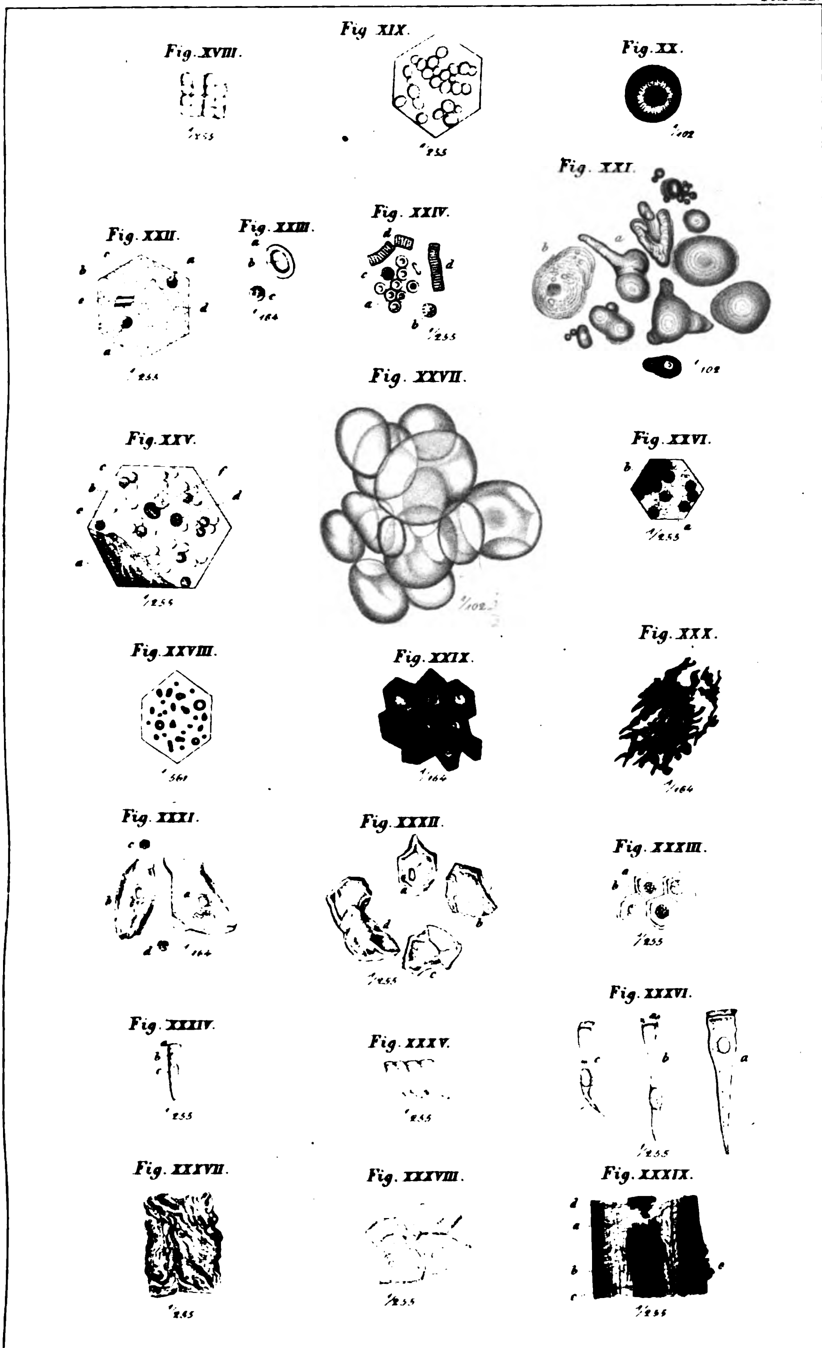

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Fig. XL.

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Fig. XLI.

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Fig. XLIII.

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Fig. XLII.

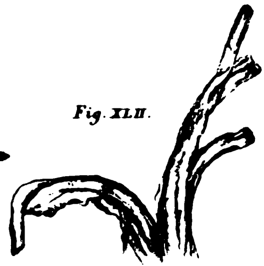

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Fig. XLIV.

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Fig. XLV.

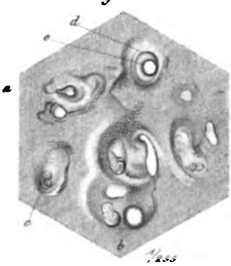

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Fig. XLVI.

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Fig. L.

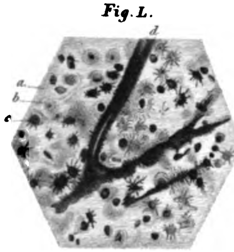

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Fig. XLIX.

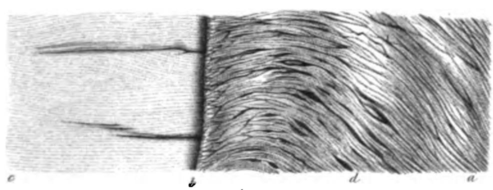

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Fig. XLVII.

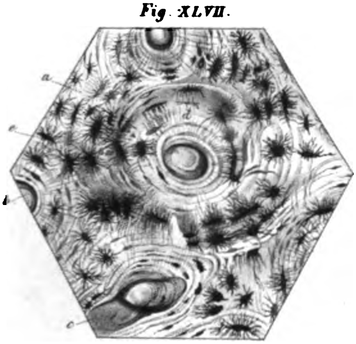

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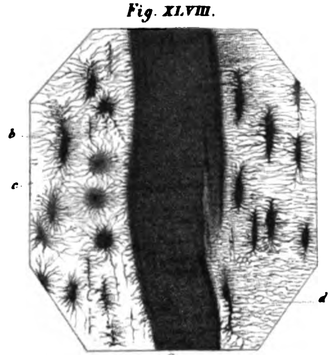
Fig. XLVIII.



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Taf. IV.

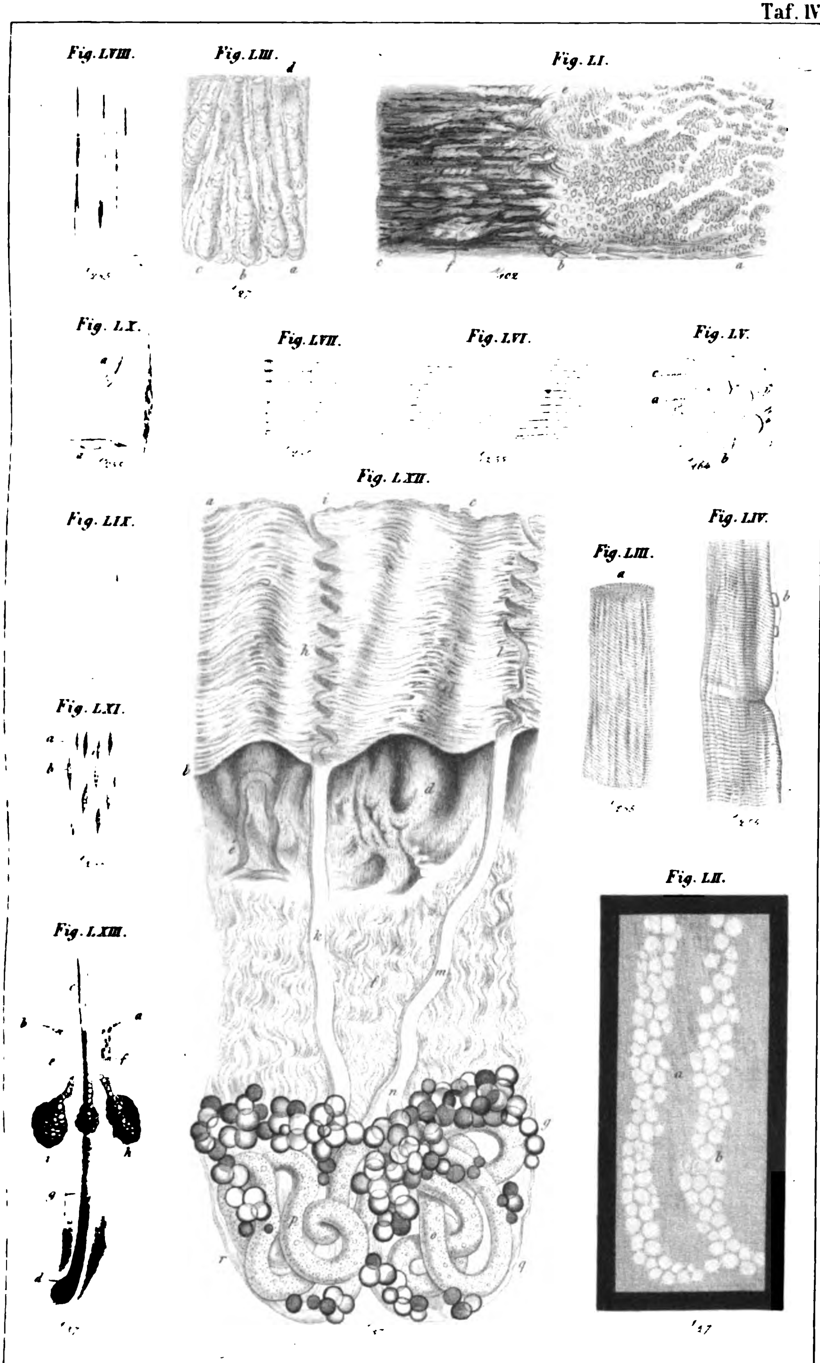

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Fig. LVIII.

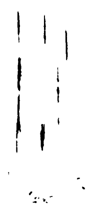

Fig. LIII.

Fig. LI.

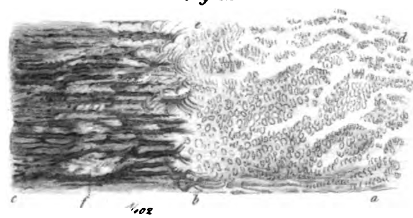

Fig. LX.

Fig. LVII.

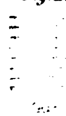

Fig. LVI.

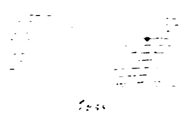

Fig. LV.

Fig. LXII.

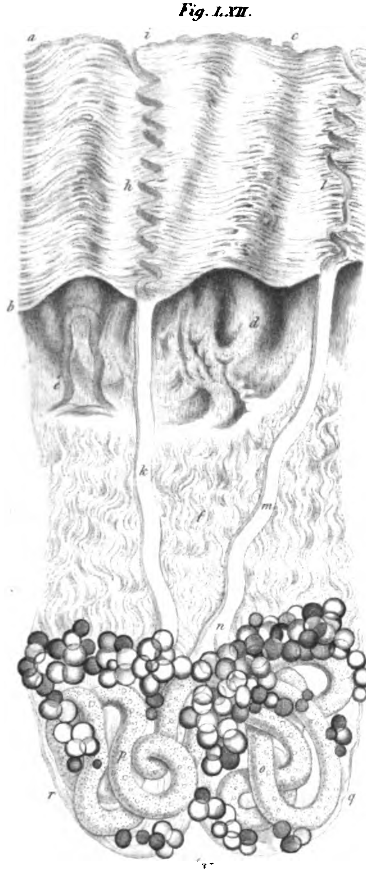

Fig. LIX.

Fig. LIII.

Fig. LIV.

Fig. LXI.

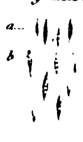

Fig. LII.

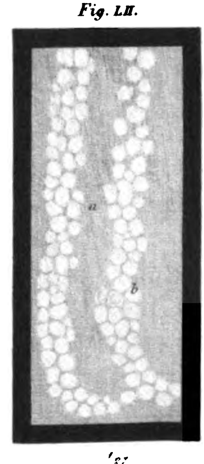

Fig. LXIII.

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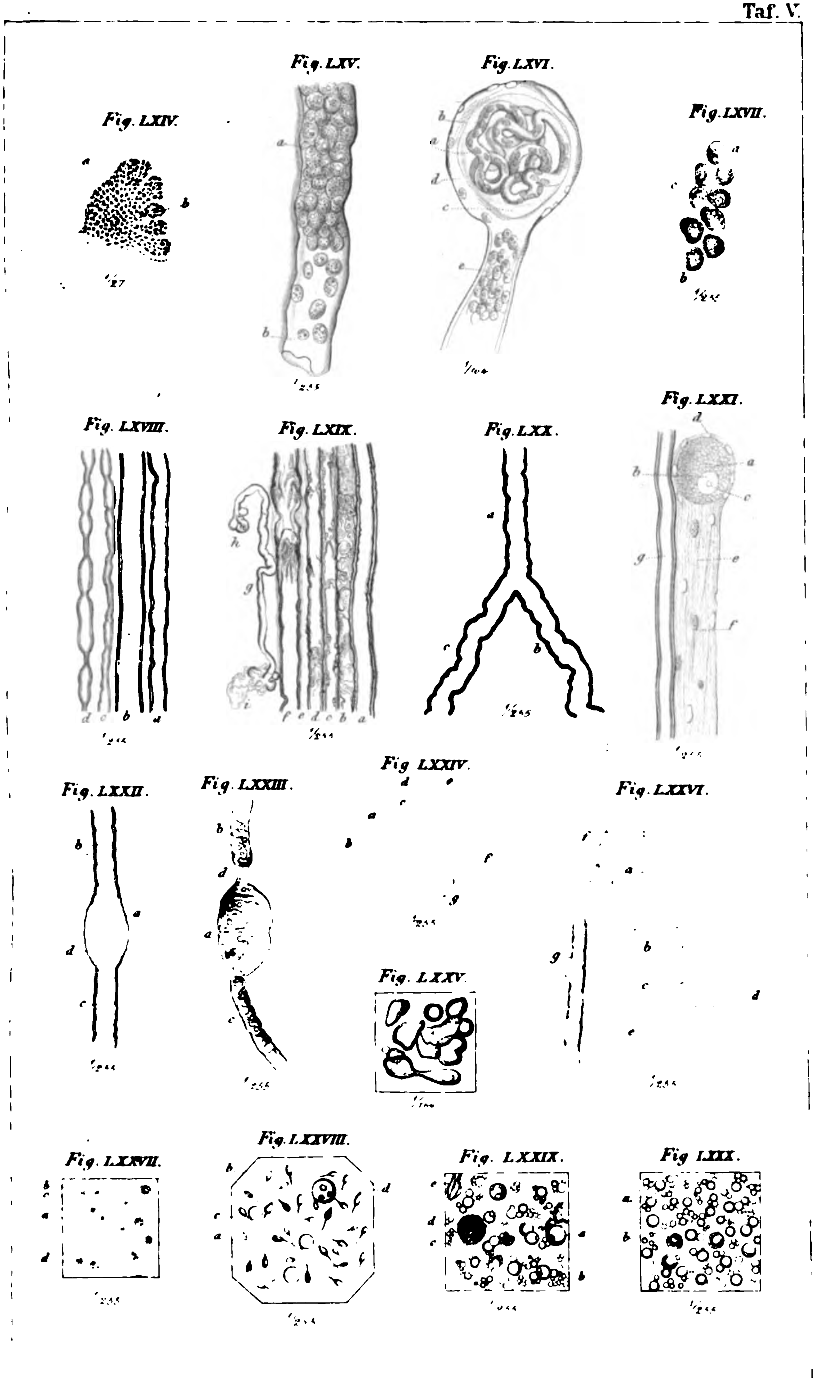
Taf. V.



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CONTENTS.

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A TEXT-BOOK OF PHYSIOLOGY.

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A TEXT-BOOK OF HUMAN PHYSIOLOGY.

CHAPTER I.

ORGANIZATION AND LIFE.

1. The different constituents of every organized being together form a nicely calculated whole, the particular parts of which only vary, within certain limits, with immediate circumstances. The mixture, the form, the arrangement, and the alteration, of the few or many substances which we meet with in every plant and animal correspond to a chief plan, which pervades all their details, and places the results in dependence on the attainable means. The *vital functions* are the visible expression of this arrangement; and health, disease, or death, are functions of the ratio of those conditions which the several molecules exhibit.

2. The capacities of self-preservation and propagation recur in every kind of living being. As it was necessary that the order of the organic world should maintain itself without external and supplementary support—as it was necessary that the individual should be able to accommodate itself to internal and external change, and preserve the species in spite of the destruction of the individual,—both of these capacities were indispensably called for. At the same time they constitute the characteristic means of distinguishing the organic creation from those contrivances which are the result of human handywork.

3. Every such apparatus requires a physical or chemical stimulus—a food as we may call it—to maintain the activity of its machinery, and thus bring about the intended effect. In this way the clock-weight conditionates the movement of the clock, the steam that of the steam-engine, and the combustion of its constituents, the light of the candle-wick. The like phenomenon recurs in living creatures. Their manifestations of force are always connected with a change of molecular proportion, or with a chemical interchange of substance. In this way particular combinations are produced, which leave the body, and which must therefore be replaced by others, in order that it may subsist. But the food thus needed not merely serves to compensate those unavoidable losses; its surplus is frequently applied to the formation of new organs, to the perfection

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of old ones, and to the restoration of lost parts. And while, in the case of our artificial contrivances, all these changes can only be induced through the instrumentality of the mind and hand of a human being foreign to the machine, organic bodies accomplish them by their own inherent forces, so that the living being fulfils, at one and the same time, the different functions of machine, attendant, and architect.

4. Since we are unable to furnish a trace of inherent independence to any apparatus we can construct, the instant the necessary food fails, it comes to a stand still. The hungry animal, on the other hand, at first withdraws the compensative matters out of the mass of its own body. Organs, on which the play of the whole depends, gradually diminish in bulk, until the too great loss of substance seriously interferes with the action of the machinery, and finally results in death. The arrangement on which this peculiarity depends has this additional advantage, that the matters once used are capable of being again employed to a much wider extent than in our machines, and are therefore only set at liberty after repeated exchanges. The conditional causes of independence are thus associated with a rule of much greater economy.

5. Reproduction is but another expression of the circumstances just enunciated. The organic being,—which possesses the capacity of applying the food it receives, not only to the nutrition of existing parts, but also to the construction of new organs, and which can defray unavoidable expenses or necessary restorations from the already existing structures of the body,—presents an embryo as an additional product of its nutrition. This embryo includes a certain sum of parts, which only require a particular food, in order that limb should arrange itself on limb, after a definite plan, until a new and independent being is created. But since the parent organisms only attain the capacities necessary for generation after a certain duration of life, the parents and their progeny are separated by an interval of time, the continual repetition of which secures the continuance of genera and species.

6. The independence of organized creatures has frequently led to the notion that the arrangement of the organism is based upon a peculiar *vital force*, which imparts to it properties differing from those of inorganic nature. It was thought that the vital functions could only thus be possible. Either this force was represented as an attendant upon a machine, who arranged at will inert substances with given properties; or it was presumed that combinations otherwise inanimate received a higher grade of activity by the communication of vital force. When this was again withdrawn, they became subject to the laws which hold good for the inorganic world; and thus after death, underwent putrefaction.

7. But the assumption of such a vital force is neither useful as affording a clue to a series of phenomena otherwise unknown, nor even harmless

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in its influence upon our ideas. It impedes a correct recognition of the fundamental principles on which the existence of living creatures is based; and leads to results which are decisively opposed by more exact physiological investigations. It separates the physical and chemical phenomena of dead and living nature by a line of demarcation which does not really exist. And although it captivates us at the first glance, by claiming a higher influence for these vital appearances, yet a more careful examination soon teaches us, that this supposition, so flattering to our vanity, prevents all insight into that much more remarkable manner in which nature accomplishes the most peculiar as well as transitory operations, by the bare use of forces everywhere present.

8. We have but to imagine that the vital functions are the result of an infinitely wise plan of organization, to comprehend all this from a simpler, more accurate, and even higher point of view. We can first of all suppose, that the embryo includes a number of conditionating causes, by means of which structures corresponding to the general object are extracted from fitting nutritive materials. In this way, for instance, vesicles or cells are produced, the properties of which react on the elements already present, and assist to determine the mode in which the subsequent food is consumed. This process is continually repeated by the physico-chemical conditions of the several parts once formed; and their fluctuating influences operate in such a way that an organism conformable to its object is continually present. The sum of the particles existing at any particular moment excites the vital phenomena then present, and at the same time conditionates those which appear in the time immediately following. And if limb be properly arranged on limb the embryo grows on, conformably to rule, and results in a vigorous being which corresponds to the perfect plan of organization. While on the other hand, if imperfections appear at an early date, the young being is crippled by a deficiency in the number and development of its organs: that only is effected which the general mass of existing structures can accomplish by means of their physico-chemical powers. So that we get imperfect, misshapen, or sickly creatures, whose capacity of life depends on the amount of opposition between what is required and what can be effected. The same obtains subsequently. The favourable or unfavourable influences only determine whether the already existing parts persist, increase, or diminish, whether the qualities necessary to the varied play of thousands of organs remain, or whether the machinery of life is arrested by their annihilation. At every instant, and under all circumstances, nature offers the sum of those operations which — to the advantage or disadvantage of the creature — are effected by the great series of microscopic elementary constituents. So that all irregular activities, degenerations, disturbances, and pains, which immediately follow them are just as necessary, and are based upon the same fundamental circum-

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stances, as those results of more favourable and healthy immediate causes, which are distinguished by their conformability to the general purpose.

9. If we regard the individual phenomena of life from this point of view—if we recollect that the smallest creature possesses a greater number of parts, and these more conformable to a specific purpose, and more intimately united to each other, than those of the most artful machine which the hand of man has produced—we shall not be surprised to find that matters apparently dead experience a transition into parts of the body, and become possessed of vital functions; and that, conversely, portions severed from the organism become subject to what are called chemical laws. And such a view at once frees us from many teleological theories, which but too often betray the childhood of knowledge, and which seek to limit all nature to the short-sighted horizon of anthropomorphous ideas.

10. The great majority of parts formed by the organism subserve more or less important vital functions, which are brought about in such a manner as is most conformable with the end in view, and are maintained with the least possible waste of matter. Still we have no right to presume that every structure must subserve a determinate and independent physiological use. On the contrary, the general arrangement of the organism sometimes causes the formation of many parts, as mere supplementary productions, in order either to their being subsequently applied suitably to a given object, or, by their origin or presence, to allow of the intermission or proper action of other organs. But the function is never the exciting cause, but only the possible result, of the production of the several constituents. It may further happen that a part is less protected, or even less adapted to its purpose than it might be, because a better arrangement of the particular organ could only have resulted from another kind, or another sum, of conditions. Just as diseases, with their lamentable results, are, under certain circumstances, the necessary consequences of the constitution of the organism, so we may often see the conflict of instincts (which are equally the mere expression of given organizations) leading to the most refined cruelties of one animal towards another—leading to actions which we, with our short-sighted view, are only too ready to condemn as wrong. Our eye remarks the subordinate masses of colouring, but is incapable of including the whole picture. We ought, therefore, never to forget, that we can but perceive particular points of the great natural whole—that we have not the capacity to trace the connection of all its mutually entangled threads. Hence we easily discover final causes which are not present, while that harmony of the thousand-fold machinery which really exists, is subject to such manifold fluctuations that it only too easily confuses our limited human capacity.

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CHAPTER II.

ORGANIC AND ANIMAL FUNCTIONS.

11. The constant physical and chemical changes which accompany life, depend upon various exchanges which are produced by the work of the different parts of the body: the extrusion of what is useless, the assimilation of what is received, and the restoration of the organs by which all these operations are effected. The whole of the *vegetable* or *general organic functions*, on which nutrition and generation depend, are repeated in every living body. It has often been supposed that all their particulars correspond in the two organic kingdoms: that there is a digestion, a respiration, a perspiration, and an excretion, in plants as well as animals. But a more accurate examination teaches that this is not the case. Vegetables possess no tissues which allow of the same kind of nutritive absorption, of distribution of juices, or of secretion, that we meet with in at least the higher animals. They have no large cavities in which considerable quantities of food can be collected, and dissolved by special fluid secretions. They possess no point midway in the movement of their juices, and no mechanism other than that of a casual and secondary apparatus for the inhaustion or expulsion of the respiratory gases. They are devoid of the changeable epithelial coverings which play an important part in many of the animal excretory organs. In one word, the general organic functions are introduced into the two living kingdoms of nature, and probably even into their subordinate divisions, by two different ways. This difference leads at once to the conclusion, that the structure of the animal is not a simple repetition of that of the plant, with the addition of a series of new apparatus. The nature of the tissues, the mode of their action and change, the form, division, and destiny of the organs,—all these rather teach us that animals of any development are constructed upon an altogether different plan.

12. Vegetables always remain passively subject to the outer world. They mutually act upon it, and are acted upon by it, only through meteorological influences, and through the ingesta and egesta of their bodily substance. Many of the phenomena of their growth depend upon the heat, the degree of moisture, and perhaps the electrical condition, of the atmosphere. From it they withdraw carbonic acid, and, in exceptional cases, oxygen. Water and the constituents dissolved in it are absorbed by them from the soil or the fluid in which they live. They give off to

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the atmosphere oxygen, and, under certain circumstances, carbonic acid, and sometimes other gases, watery vapour, and volatile organic or inorganic combinations. They allow different kinds of fluid mixtures to transude and appear on their surface. But all independent perception of the things around them, and all voluntary change of place, are completely absent. The phenomena of movement which are here and there manifested in the vegetable kingdom do not depend on a voluntary principle. Light and heat, and, in many cases, a particular time of the day, constitute the general conditions under which they occur.

13. It is the distinguishing characteristic of the animal that it recognizes the objects which surround it, that it enters into manifold and independent relations of exchange with them, and that it makes use of them to a great extent at will. An active personality, and a free will, dictate and pervade its most frequent and important relations to the external world. So that we find here special *animal functions* which allow of the reception of impressions, of the change in place of particular parts or of the whole organism, aud finally, of mental emotions. The senses, together with the organs of locomotion,—which can be subjected to a self-calculated guidance,—and the nervous structures, complete the circle of those organs which subserve the highest vital manifestations of the animal, and whose actions have no parallel in the vegetable kingdom.

14. These apparatus are also of essential service to those parts which are the seats of the general organic functions. The contractile tissues which belong to the general plan are frequently made use of to introduce or expel food, respiratory gases, juices of the body, secretions, and even the developed embryo; to alter the phenomena of nutrition by changing the porosity of particular parts, or to accelerate many processes of metamorphosis.

15. In the series of functions met with in man and the more highly organized animals, that of *digestion* elaborates the food, while the useless remainder, mixed with excretory matters, is rejected in the fæces. That of *absorption* provides for the transmission of whatever is to be added to the blood—the mother-fluid of nutrition. The *circulation* sends this in closed canals throughout the body, in order both to the maintenance of the particular parts, and to the renovation of the fluid itself. The *respiration* effects the greater part of the exchange of its gases, while the *cutaneous transpiration* repeats the same occurrence on a smaller scale. Besides this, watery vapour and other matters are thrown off both by the lungs and the skin. The organs of *excretion* offer certain secretions, which are either destined to leave the body immediately, or may serve other purposes, and then be discharged, or may, when wanted, be returned into the mass of the blood. Finally, *nutrition* maintains, increases, or diminishes the mass of the constituents of which the entire

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organism is composed: and forms in this manner the result of the general organic functions of the animal being.

While the *senses* receive the impressions of the external world, the *phenomena of motion* lead to the change in space of particular parts, or of the entire mass of the creature. The *organ of voice* results from a suitable connection of the organs of respiration and movement. The *nervous* system, which receives and elaborates excitements, coerces the muscular fibres to contraction, and constitutes the immediate instrument of the mental functions, while it at the same time exercises a mediate control over most other organs of the body, since it can alter their movable pieces within certain limits.

Generation and *Development* certainly belong to the general organic functions. But since they do not subserve to the maintenance of the individual, but to the preservation of the species, they have been very properly separated from the remaining phenomena of nutrition. The description of the evolution of the embryo belongs, however, to an especial branch of science, to the history of development.

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CHAPTER III.

INDEPENDENCE OF THE VITAL MANIFESTATIONS IN ANIMALS.

16. The physical and chemical contrivances of our body often closely correspond with those of an artificial apparatus. The heart may be compared to a pump provided with suitable valves, the arteries to elastic conducting tubes, the eye to an optical camera obscura, and the organ of voice to a tongued musical pipe. The bones and muscles work like levers and tractile forces, while at least many organs of secretion act in part like a filtering apparatus. And just as we seek to promote evaporation by increasing its surface, and removing the air already saturated with watery vapour, so something very similar to this recurs in the lungs of man and animals.

17. But if we compare any such apparatus with those which nature exhibits in the animal body, we find that the latter are distinguished not only by a far greater adaptation to their ends, and by the advantage of self-maintenance already mentioned, but also by the independent and manifold character of their operations. The muscles with which they are provided, and which are regulated by nerves, render them capable of shifting and adjusting themselves, while the machines which we contrive exhibit a more or less permanent helplessness.

For instance, the rays of light experience such a diversion in the eye that the focus of the images of objects at suitable distances lies on some part of the retina; and we can easily construct an artificial eye, the semi-transparent back-ground of which repeats this arrangement; but the hand of the observer must be brought to its assistance, just as in the telescope and microscope. It must shift the instrument so that the rectilinear rays of light enter the dioptric apparatus. It must insert screens, provided with greater or smaller openings, so as to regulate the mass of the entering light. It must alter the mutual distance of the lenses, or change certain of the refractile media, so as to obtain distinct images of objects at different distances. While our organ of vision can itself provide for all this series of improvements on the instrument, the muscles of the eye move the eyeball as it is required for the sight, the iris, which plays the part of a screen, enlarges or contracts its aperture according to the quantity of the entering light. And certain other changes allow of our distinctly recognizing objects both far and near. In one word, our organ of vision forms a much more independent con-

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trivance than any dioptric instrument which human industry has ever been able to construct.

18. And frequently, Nature requires but one organ to accomplish that for which we find many necessary. One and the same muscle can produce the most varied attitudes of the parts which correspond to it, according as it varies its point of action. Since the phenomena of filtration depend upon the size of the spaces which the filter offers, and since the capacity for diffusion additionally varies with the nature of the porous body, the different membranes of our body can altogether change their operations when their contractile tissues are drawn together, or when nutritive phenomena lead to the deposit of different matters in their substance. The contraction of the muscular fibres is intimately connected with certain changes of their molecular properties, and thus with a complete alteration of their physical condition.

19. This automatic change in the condition of the several organs pertains to that series of phenomena to which animals owe their greater independence. But since for the most part it only completes and perfects functions otherwise possible, or diminishes the number of contrivances required, it is not so essential as self-maintenance and reproduction. The comparison of plants and animals plainly shows how Nature makes use to this end of substances which, even without this requirement, would necessarily be present, and thus seeks to derive from them the greatest possible amount of advantage. The rigid tissues of vegetables are much less fit to construct any movable apparatus than the soft contractile elements of the animal creation. And hence this self-improvement is much less frequent in the former than in the latter.

20. In contemplating the phenomena of the nutrition and growth of living beings, we are struck by a certain visible independence of particular tissues. The mixture which transudes the walls of the blood-vessels in order to distribute itself amongst the other tissues—the nutritional fluid, as we may call it—reaches the most various elements of the corporeal organs, where they lie close to each other. Yet in spite of this, the muscular fibre selects from it materials altogether different to those chosen by the neighbouring nerve-fibre, and these again differ from those taken up by the mass of areolar tissue which encloses them both. This phenomenon has been named the *organic attraction*. But it is not necessary to adduce special vital forces to assist in explaining these circumstances. The mere arrangement of the parts, and the properties which they already possess, make it quite conceivable why the muscular fibre, rich in fibrine, exhibits different elective affinities from the nerve-fibre, which is filled with a mixture of oil and albumen. Indeed, one sometimes sees how Nature proceeds deliberately, step by step, to allot to every tissue its proper combination. The epidermis consists of a number of cells deposited in a stratiform manner. The outermost layers contain the most

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horny matter, the middle, less, and the most interior, least of all. The most internal substratum is formed of nuclei and cells, rich in albumen. The blood-vessels are distributed solely beneath the epidermis in the mass of the corium. The nutritional fluid furnished with dissolved albuminous substances, in passing out of the vessels, first reaches the nuclei and albuminous cells which lie next to the corium. When it has here given off the proper materials, and has undergone a corresponding change, it passes to the least horny layers, so that these increase their mass. Finally, the oldest horny cells only get that which the younger and needier ones have already rejected as superfluous.

21. Many of the functions are complementary to others, so that a single task, as it were, divides itself, to be discharged by a number of different organs. For example, the matters which are to be removed from the blood, and then from the body, divide themselves according to their cohesion. The gases and vapours pass out by the lungs and the skin, and the liquid portion chiefly by the urine. Just as the heavier scale of a balance goes down, and the lighter flies up, so the quantity of the urine is increased according as less water is evaporated by the skin and lungs; while, on the other hand, when the sweat drives off more fluid, other circumstances being equal, less urine is secreted. We have here a quantity composed of two varying members, which always endeavour to give about the same sum.

22. These fluctuations of equilibrium are sometimes connected with certain relations of adaptation. The woman capable of childbearing discharges every month a certain quantity of blood from the organs of generation. When she becomes pregnant this evacuation ceases. In this way, a part of the matters formerly excreted is rendered applicable to the embryo. When the child is born, that surplus of the fluids which is no longer given to the embryo, is determined to the breasts. These organs furnish the milk, provided that the act of suckling excites and maintains in them an increased activity. During this time, the menstruation remains absent. But on the contrary, if the milk is not suckled from the breasts, it soon disappears; and, on the inactivity of these glands, menstruation again appears.

23. If we limit our attention to shorter intervals of time, we shall find the same striving after equipoise in all the phenomena of nutrition. Following the weight of the body of an adult man from day to day, we shall find that the differences are usually not greater than one fæcal and one urinary evacuation. And in most instances, something of the same kind may even be observed when a man or an animal increases or emaciates. The small daily increments and decrements which here obtain only form more considerable and visible values by being added together in large numbers. The organs of reception and extrusion are so arranged that, as a general rule, the corporeal mass is never suddenly altered, but

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income and expenditure are very nearly equal, if we limit observation to a small space of time. We have a regular clock-work, which is always correct within a certain limit, and which strives to maintain its ordinary rate in spite of many disturbances.

24. This latter circumstance has frequently led the physician to assume a *natural healing power.** The organism itself was supposed to possess the capacity of getting rid of certain morbid matters by means of crises, so as finally to recover the freedom of its ordinary healthy play. But closer observation teaches that the entire opinion is based upon a mistake. The course of every disease which is left to itself, depends immediately on the condition of the parts of the body. If these elements are so degenerate as to afford none but abnormal or even disturbing results, their destruction follows as a matter of course. No counter-plan exists which could restore them. In such a case there is just as little of a natural healing power, as there is of a vital force for the ordinary circumstances of life. But, on the other hand, it may certainly happen, that the variable organs of excretion may take on an activity, which is greater than that of their immediately preceding operations, and that this disturbance of equilibrium may unload other parts, and so allow of a return to a more regular activity. In this way the sweat or the urine may take up and discharge the fluid of dropsical effusions, or a diarrhœa may counteract an effusion which loads the brain, or means which promote absorption may discuss solid deposits. But all these phenomena are the results of the conditions naturally or artificially present, and are not the consequences of a special remedial plan, or of a special force, opposed to disease, and previously present in the organism.

25. Every animal has a time for development and growth, a period of middle life, in which the body strives to maintain an unaltered mass, and an epoch of decrease, which is concluded by natural death. These periodical changes are explained by the mode of arrangement which prevails in the organic creation. The younger elements can always so elaborate their surplus as to produce from it new and suitable tissues. The older are only capable of maintaining themselves. And gradually their energy sinks, so that finally their mass diminishes. And if there are many changes connected with definite years of life, the dates of which only fluctuate within certain limits,—such as the milk and permanent teething, the appearance of puberty, the cessation of menstruation in old women; this may be explained as due to the fact, that such phenomena constitute the necessary results of certain stages of growth, and follow inevitably from the previous and accompanying conditions. A truly periodic repetition cannot be distinctly made out.

* Commonly termed the *vis medicatrix naturæ.*

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26. In many functions, however, and especially in those of the sexual organs, periodicity does appear. The rutting season of many animals recurs only at regular times of the year. Meteorological and other circumstances, especially temperature, often exert a visible influence in this respect. But since many creatures prepare during the cold of winter for the approaching rut of spring; and since woman menstruates every four weeks during all seasons indifferently, it follows that these fluctuating phenomena must be based upon other causes than the surrounding temperature. But it does not follow that the female organism derives this periodicity from itself, or that it would obtain if we could remove all other influences without destroying the living being. We shall rather find that these phenomena of regular recurrence are probably connected with causes which do not exclusively lie in the organism.

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CHAPTER IV.

PHYSICAL PROPERTIES OF THE HUMAN BODY.

27. The small size and extraordinary number of the pieces with which Nature works in the animal creation, ensure a number of advantages, which we are unable to attain to the same extent in our artificial contrivances. The various tissues which enjoy the functions of separate organs require the aid of the microscope to be seen, and even its highest magnifying powers are often insufficient to expose all their more influential constituents. What we call an organ is only the determinate aggregate of a large number of microscopic tissues of various kinds, every one of which possesses its own special function. The limits of our senses render it impossible to form the remotest conception of this vast arrangement of microcosms.

28. Any exact estimate of the number of histological elements which go to a given part is met by insuperable difficulties, since their form corresponds to no simple mathematical figure, and their sizes and distances, and the minuteness with which they are divided, vary remarkably, even within small extents of space. The investigation has a yet more uncertain basis when foreign tissues intervene between those which constitute the essential characteristics of the organ. With the exception of a few organs, as, for instance, the muscles, there is scarcely any means of accurately estimating the number of these tissues. But even the vaguest estimates suffice to show that the higher animals may possess, in each of their larger organs, millions of separate physical and chemical laboratories.

Harting has calculated that in the adult on an average 700,645 to 789,677 epidermoid cells (Tab. II. Fig. 32) are collected in the space of a square inch. Now since the surface of the author's body amounts to about 2325 square inches, there are 1750 millions of horny cells in a single layer of epidermis. But even the parts where the skin is thinnest have more than one layer. They possess at least more than a dozen of such strata, each of which exhibits more than a billion of small horny scales, complete in themselves.

The air-tubes of the rabbit sustain about twenty millions of cilia, and those of man about one hundred and fifty millions, each of which is in perpetual movement. The fat of the adult appears to be somewhat less minutely divided than that of the new-born infant. Yet, in

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spite of this, there would be about * sixty-five millions and a half of fat-cells (Tab. II. Fig. 27) in the space of a single cubic inch. According to Harting the most superficial layer of the crystalline lens in a woman, whom he examined, contained two thousand lenticular fibres (Tab. I. Fig. 56), and the entire choroid of the eye about eleven millions of pigmentary cells. (Tab. II. Fig. 29.)

According to Rosenthal the roots of the human cerebral nerves contain more than a hundred thousand primitive fibres, and it is probable that even this estimate is too small. If we add to these the spinal nerves, and consider that many of these fibres divide in their further course, we again get a number of several hundred thousands for these conductors, which, after all, do but work the biddings of the mental emotions on the peripheric part of the nervous system. According to Harting the median nerve of the adult includes from twelve thousand to twenty-one thousand primitive fibres, and the femoral nerve twenty-one thousand to fifty thousand.

29. But it is only the person unacquainted with other natural phenomena who will be astonished at these numbers. Wherever we go, we come upon quantities, which our limited faculty of apprehension generally regards as infinitely large. Although light courses through one thousand millions of feet in a second, and the length of each separate undulation amounts on an average to about 1-50,000th of an inch, yet a ray of light which comes from a star of the twelfth magnitude, or from a star on an average 3261 times removed, requires about four thousand years in order to reach the earth. On the other hand, the above-mentioned animal tissues contain a number of different subordinate constituents, the smallest of which cannot be recognized even under the most powerful microscope. The ultimate molecules of all bodies have so small a size, and are so similarly composed, that the eye of man will never be able to see them.

30. But it is not so much the number, as the systematic arrangement and union of its different pieces, which makes the organic creation so wonderful. Nature has so arranged every organism that it everywhere operates in limited spaces, which are not only the smallest possible, but are, to a great degree, independent of each other. This arrangement leads of itself to many important advantages to which we shall return again. But it is so intimately connected with the very nature of things that it recurs in even the most unimportant circumstances. For instance, when the carbonate of lime contained in the lime-saccule of the frog is precipitated we obtain minute crystals, the greatest of which has a maximum diameter of less than 1-1000th of an inch, while on the other hand the smallest are less than 1-15,000th. (Tab. I. Fig. 6, 7.)

31. The enlargement of the free and active surface constitutes one of the most striking advantages of this subdivision into smaller masses. A

* 65,541,537.

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pulverised body is dissolved much more easily than an entire piece of much larger size, because more molecules of the solid and the fluid substance are brought into mutual contact. The smallness of the blood-corpuscles (Tab. II. Fig. 24) floating in the blood thus enables them to exercise the most extensive reactions on the mother-fluid which surrounds them, and on the gases which they have taken up. In man their average diameter amounts to 1-3600th of an inch, and their medium thickness to 1-15,000th of an inch. In this way nature greatly gains in active surface, since at the same time that the entire mass of blood-corpuscles is divided into rolls of 1-3600th transverse diameter, these are again separated into discs of 1-15,000th in height. But since the upper and under surface of the blood-corpuscles are either somewhat hollowed out, as in man, mammalia, and some fishes, or elevated, as in birds, reptiles, and certain other fishes, it is evident that this circumstance still further increases the surface than if every blood-corpuscle had exhibited the level surfaces which bound the ends of a mathematical cylinder. And hence we may conjecture that those animals which possess smaller blood-corpuscles, with proportionally more extensive surfaces, and which have also a much * greater number of them, are endowed with a greater activity.

The subdivision of the mass of blood leads to similar phenomena. The circulating blood fulfils two objects. It gives off matters to the various tissues of the body, and, in the lungs and skin, exchanges certain elastic fluid compounds with the atmosphere. Both of these functions are increased when larger surfaces of the blood come into contact with more extensive walls of vessels. The finer canals of the capillary vessels are therefore interposed between the larger conduit pipes of the arteries and veins. The smallest capillaries of the retina and brain, when filled with blood, measure, according to Henle, 1-5000th of an inch, and are 2700 times finer than the aorta at its commencement. It results from hence that the surfaces of contact would be multiplied in exact proportion with the walls of the vessels, if we regard as invariable their length and the mass of the blood. But since capillary vessels, which are almost half as fine again as those above-named, occur in some preparations which have been artificially injected and thus over-distended, and since the arteries and veins only experience a transition into capillaries by gradual and successive divisions, it follows that the enlargement of surface which Nature obtains by means of the capillary system must be even more considerable.

The secreting glands offer a third example of the great advantages thus obtained by Nature for particular organs. They constitute a number of

* The original has "equal or even greater number," and hence the Editor feels bound to explain why he has altered these words to "much greater." Dismissing the less measurable influence of concavity or convexity, one may broadly state that to give an equal total surface and total activity, the number of blood-discs should be inversely as some power between the square and the cube of their diameter. The influence of minuteness in increasing activity would therefore presuppose an increase of number even exceeding this.

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coiled, or arborescent and branching, tubules. We shall hereafter see how greatly the cavitary surfaces of these secreting canals may thus be increased. At present we will only adduce in illustration that a square inch of mucous membrane from the stomach of the rabbit contains about 451,600 gastric glands, and that the average secreting surface of both kidneys, which only amount to from 1-148th to 1-246th of the corporeal mass, is about six times as large as the whole outer surface of the skin.

32. A consideration of the physical and chemical properties of the particular tissues will show us many other advantages dependent upon the division of the organic implements into microscopic and independent pieces. And both this and the study of their several functions will prove at every step, that the small size and large number of these agents of the vital actions essentially contribute to the exquisite perfection of their operations.

33. The pliability of most of the organs depends in great part upon the considerable quantity of water which they contain. If muscles, tendons, and other soft tissues are thoroughly dried, they form brittle masses, which may not unfrequently be broken like glass. But if they are again softened by immersion in water, they recover a great part of their original flexibility.

About three-fourths of the entire weight of an animal is composed of combinations, which volatilize at a temperature of 212° Fahrenheit. A frog was killed under olive oil, and carefully cleaned. In the fresh state it had weighed 461 grs., but after undergoing desiccation it left a solid residuum of only 84 grs., or 18 per cent.; so that the process had deprived it of nearly 5-6ths of its weight.

34. The fluids of the human body obviously contain more water than the solid structures. But the quantity of this substance varies in a very high degree with the circumstances of excretion and nutrition. Taking the ordinary estimate, the blood, which usually contains about 70 to 80 per cent. of fluid matters, constitutes as it were the neutral ground between the fluid and solid constituents of the human body.

Evaporation to dryness withdraws from the sweat and mixed saliva about 99 to 99¾ per cent. of fluid ingredients. The liquor amnii, the gastric juice, and the aqueous humour of the eye have 98 to 99 parts: the lymph, the semen, the pancreatic fluid, and the mucus of the nose, 90 to 97: and, finally, the bile, 87 to 90, and the milk, 83 to 92 per cent. The watery ingredient of the urine varies according to circumstances, but is in general 93 to 98 per cent.

The loose areolar tissue, which is saturated with the general nutritional fluid of the body, gives 80 per cent.; the brain, 75 to 78; the glands and the muscles, 72 to 79; and the cartilages, ligaments, tendons, and crystalline lens, 57 to 70 parts. Even clean fresh bones lose more than 14 per cent. when placed in the water-bath.

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35. External appearance frequently deceives us with regard to the watery content of bodies. Substances which appear to be quite dry often lose a considerable quantity of their weight when exposed for some time to a heat of from 212° to 258°. Powdered crystallized cane-sugar only gives off a very inconsiderable quantity, for instance, ·6 per cent., and even this is probably due to watery vapour, or some other volatile substances contained in the interstices of the fine powder: while hartshorn contains 14½ per cent.; and bread, in its ordinary state of dryness, 43 to 46 parts.

The specific gravity of the different constituents of the animal body —*i.e.*, the proportion of their weight to their cubic contents—varies within rather narrow limits. A given quantity of water (1 cubic inch) has, at its temperature of greatest density (39½°), a certain weight (253·5 grains). Taking the specific weight of this water as a starting point, we need only divide the quantity of grains which any other mass weighs, by the number of cubic inches which it contains, in order to get its precise specific gravity.

36. There is but one large ingredient of the human body which is lighter than water. The specific gravity of the human fat amounts only to ·932. There is no fluid of our organism which has a specific gravity of exactly 1·, or that of distilled water, since every one of them contains dissolved solid ingredients. The bones, which have the highest specific gravity, scarcely reach double that of pure water.

37. Here again we find the blood, with a specific gravity of 1·06, forming a line of partition between the fluid and solid constituents of the organism. Those mixed fluids which contain a large quantity of water, as the liquor amnii, the saliva, the gastric juice, and the urine, range from 1·004 to 1·02. The bile, the lymph, and the milk have a gravity of from 1·02 to 1·04. The brain, the specific gravity of which is diminished by the amount of its fatty constituents, also amounts but to from 1·009 to 1·03.

Animal structures which are soaked in a large quantity of nutritional fluid not unfrequently exhibit specific gravities less than the average of the whole mass of blood. For instance, the gravity of certain muscles amounts to 1·020, while that of many nerves is 1·040. But with these exceptions, we shall find that the estimates for the solid tissues of the body hitherto examined, either surpass the average specific gravity of the blood, or are at least equal to it. Thus, that of the arteries amount to 1·06—1·10; the veins, 1·08—1·11; the nerves, 1·05—1·13; the tendons 1·11—1·13; the cartilages, 1·1; the fresh bones covered by their periosteum, 1·2—1·5; while cleaned bones, and fragments of compact substance, reach a gravity of 1·9—2·0.

38. The medium specific gravity of the whole body is of course determined by that of its particular constituents, compared with their absolute

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quantities. Thus a disproportionate amount of bone, or of other solid tissues, may raise the general specific gravity, while, conversely, it is lowered by large fatty deposits.

39. Frogs examined in spring, during their rutting period, gave an average specific gravity of 1·03 to 1·04: three mice, ·96 to 1·09. An eight months' child, which had lived two days, showed a gravity of 1·008. But the adult, which is provided with a stronger and heavier skeleton, has a somewhat greater average gravity: and 1·06 to 1·07 would probably be the estimate nearest to the truth. This does not much differ from the specific gravity of the blood. Disregarding differences of sex, we may estimate the weight of a human being of thirty years old at 130 lbs.: according to which valuation the cubic capacity would amount in round numbers to 20 cubic feet.

40. Every man is able to alter his specific gravity in an instant, by drawing air into his lungs. Regarding water as unity, the specific gravity of the air amounts to ·001299: that is, it is nearly 770 times as light. So that air has a much greater power in lightening the body than any arrangement of cork, which has a specific gravity of ·24. But since the quantity of air which we are able to take into the lungs is but a small one, it follows that we cannot produce any very great difference in this way.

41. Sea-water has a specific gravity of 1·03. River-water is something less. Hence man sinks in both of these, so soon as he is completely immersed, unless he sustains himself from time to time by appropriate movements of the body. And the inhalation of the greatest possible quantity of air into the lungs enables him to keep on the surface much more easily. But the capacity of the lungs is not sufficient to allow of the reception of such quantities of air as would lower his specific gravity from 1·065 even to 1·03. The appearance of the bodies of drowned persons on the surface of the water is probably the result of three contributing causes: the increase of their volume in the water, the dissolution of their substance, and the access of putrefaction; the latter chiefly acting by the gases developed during the process.

42. Large deposits of fat (Tab. II. Fig. 27) lower the specific gravity in proportion as they predominate over the other parts, and especially over the bones and the muscles. In rare and exceptional instances, the extraordinary fatness of a man enables him to float like a cork on the surface of sea-water.

43. It is usual to express the cohesion or absolute solidity of a solid body by the weight which suffices to rend asunder a mass of definite thickness. Thus we will suppose that a cylindrical wire, whose transverse section amounts to 3-1000ths of a square inch, hangs perpendicularly from a fixed upper end, and requires to be loaded with a weight of 330 lbs. before it is torn asunder at any point. We may therefore state its

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cohesion, as the amount of weight required for 1-1000th of a square inch, or as 110 lbs.

44. But the body made use of in these experiments is subject to a double burden. It is not only laden with the weight which we have voluntarily added, but every upper part has to suspend all those which lie beneath it. Thus a metallic wire must tear asunder without any foreign burden, when the weight necessary to its disruption is supplied by its own mass. For instance, supposing it to be of iron, with a specific gravity of 7·5, and a cohesion of 110, this event would necessarily occur as soon as there were more than four miles of length, with only 1-1000th of a square inch of transverse surface.

45. Thin iron wires have a greater cohesive value than thicker ones of the same composition. If the solidity of the moist animal tissues similarly increases with the enlargement of their surfaces; the division into microscopic fibres or scales (Tab. III. Fig. 40) will have the effect of vastly increasing the resistance.

46. One hundred threads, which are properly united into a cord, will bear more than one hundred times the weight which each separate one could sustain. And where nature has united many thousand of the finest elements of the tissues into a whole, the solidity of its organs will thus gain an additional increase.

47. Flat ropes are stronger than round ones of the same nature. Many of the hairs of the head, and a large number of the tendons, which have an oblong instead of a circular section, are probably thus endowed with more strength.

48. It often happens that two parts which consist of precisely the same tissues yet essentially differ in cohesive force. The one may be nine times as strong as the other. These differences are partly inherent, partly, however, depend on the way in which the experiments are made. The original differences of the molecules, the mode in which they are united to each other, the compressed or diffused subdivision of their bundles, the mixture of more or less solid constituents, and the more or less favourable form of the entire mass—all these circumstances cause many of the differences which we meet with on comparing a series of dead bodies, or a number of corresponding parts in the same body. Inequalities in length, deviations from a simple mathematical form, the access of putrefaction after death, and the way in which tractile weight acts upon the particular microscopic elements,—these circumstances equally increase the fluctuations which, in spite of the greatest care, appear in such experiments.

49. Thin leaden wires have on an average 2·7, copper wires 27·5, and iron wires, with a transverse surface of 1-770th of a square inch, 76·2, of comparative cohesive force. Very thin threads from the cocoon of the silk-worm, consisting of 8 to 10 microscopic filaments, gave a force of

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28, and a well twisted silken cord 42·5. If we compare these with the results which Wertheim [2]) and myself obtained with different portions of human corpses some days after death.

Part.	Cohesion.		Part.	Cohesion.	
	Mean.	Extremes.		Mean,	Extremes.
Muscles .	·06	·02 to ·13	Tendons . .	5·3	2·3 to 10·4
Arteries .	·14	·1 to ·2	Bone (after Wertheim)	8·	4·3 to 15·
Veins .	·23	·1 to ·3			
Nerves .	·98	·6 to 3·5	Bone (after Bevan)	37·9	25·11 to 75·81
Hair .	9·9	—			

The sequence in which the particular tissues are here placed corresponds to a general increase of cohesion. But we may remark that the absolute solidity of no part of the animal body equals that of the thin iron wire: even that of the silken cord is considerably below this substance. All the supplementary advantages which the organic tissues enjoy cannot compensate for the original difference in the nature of their molecules.

50. But we must not think it an imperfection that no part of our body is made as strong as iron. We shall hereafter point out what important properties are in this way acquired. And, in spite of this deficiency, those parts of the body which have to support great weights are constructed of such a strength that their cohesion is far beyond their most extraordinary requirements. Even taking the lowest valuations given above, we find that it would require more than seven-fold the weight of the whole body, or more than eight hundred and eighty pounds, to tear the extensor tendons of the foot. And if, in exceptional instances, this rupture of continuity is effected by convulsive contractions of the corresponding muscles, this fact only shows what enormous force the shortening of these organs is able to exert.

51. If a suspended body be laden with a continually increasing weight, it is as continually elongated, until finally, it ruptures at the weakest place. But if the weight be removed before this happens, it endeavours to return to its original length. If it succeeds in doing this, it is perfectly elastic; but if, on the other hand, it remains permanently elongated to a certain extent, it possesses only an imperfect elasticity.

52. One and the same body may exhibit both of these properties with different weights. A strap, for instance, which is originally 4-5ths of an inch long, can return to its previous length after a temporary weight of 28¼ drachms. But if laden with 34 drachms, it will only return to a length of 24-25ths. So that 28¼ drachms indicate the limit of its complete elasticity. That of the incomplete elasticity obviously coincides with the limit of cohesive force.

53. Simple as these circumstances may appear, there are many diffi-

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culties which prevent their correct determination. Molecular composition, temperature, the mode of applying the weight, and the duration of its application, greatly influence the results. There are many substances which, immediately after the removal of the weight, only shorten to a certain extent, although their length subsequently undergoes a considerable diminution. Silk and most parts of the human body behave in this way.

54. As regards the elongations produced by different weights, they are of two kinds. They either increase regularly or irregularly with the weight. The soft structures of the human body offer in this respect a peculiar phenomenon (Fig. 1). In order to exhibit the fact mathematically, we may consider the increasing weights as the abscisses, (*ab*, *ac*, *ad*, Fig. 1), and the corresponding elongations as the ordinates, of a curve. Now if both increase in the same proportion, so that the proportion of *b e* to *c f* is equal to that of *a b* to *a c*, the line of elasticity will be a straight one; since the corresponding sides of similar triangles vary in proportion with each other. But if this is not the case, if, for instance, the elongations *b h*, *c i*, *d k*, increase disproportionately to the weights *a b*, *a c*, *a d*, the line of elasticity will be a curve, the course of which will depend on its abscisses and ordinates.

FIG. 1.

Many inorganic bodies offer us the simplest of these two cases. Their elongations increase in exact proportion with the weights; they, therefore, possess a straight line of elasticity *a e f g*. According to Wertheim and Chevandier, this holds good for wood, and also for bone, especially for dried pieces of its compact tissue; while, on the contrary, the soft tissues of the human body invariably exhibit a curved line of elasticity, which, according to Wertheim, corresponds with an hyperbola *a h i k*, so long as no immoderate weight is applied. The quantity of their watery constituent forms a very essential cause of this phenomenon. If tendons or nerves are dried in the air, their line of elasticity approximates to a straight one.

55. If a cylinder (*A B C D*, Fig. 2) possesses a straight line of elasticity, we may get the simplest idea of its extensibility by taking the weight (*P*), reduced to a certain unit of transverse section, and required in order to extend it to twice its length. If its extensibility and compressibility are proportionate to each other, the weight *P*, laid upon *A B*, will bring the cylinder *A B F G* again to half its length, or will restore it to *A B C D*. The idea of a coefficient, an index, or a scale of elasticity, is based upon these assumptions. We designate by these words the weight compared with an unit of transverse section, the tractile forces of which would double the

FIG. 2.

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original length of a body, while its compressing force would reduce it to the half.

56. This index of elasticity has frequently only an ideal value, since there are many substances which tear rather than elongate to twice their length. And in many instances, even where highly elastic bodies are concerned, its estimate rests upon an inaccurate basis, since the capacities for extension and compression do not go hand in hand. This is especially the case with bodies which are mixtures of different kinds of constituents. Finally, when the line of elasticity does not form a straight line, or a curve which may be mathematically estimated, it does not safely exhibit the extension for additional weights.

57. In applying this method to the constituents of the animal textures we meet with as many varieties as were previously found in the amounts of cohesion (§48). Wertheim obtained 1·15 lbs. for the membrane of the human femoral artery when reduced to 39·4 inches in length, and ·0016 square inch of transverse surface. The femoral vein had 1·85 to 1·94 lbs.; the sartorius muscle ·574 to 2·8; various nerves of the thigh 22·17 to 71·53 lbs.; the tendons 283·27 to 442·36; and strips of the compact tissue of the thigh and fibula 4013 to 5979. Ludwig found 1·99 to 3·2 for transverse strips of the arch of the aorta in the horse, and 2·87 was found by myself for the same part in the cow. According to Wertheim the result in the dog was only ·8. Pieces of arteries at a greater distance from the heart invariably gave a smaller value than the arch of the aorta.

58. Very much depends on the fact whether the parts have or have not previously been displaced. If they have once exceeded the limit of their complete elasticity, the weight first laid upon them must also have thinned them, either generally or in some particular places. They also undergo a smaller extension on the application of further weights. Each of these causes contributes to raise the index of elasticity very considerably. For instance, a square strip from the aorta of the cow, presented at first only 2·7; but after passing the limit of complete elasticity, it amounted to 6·9.

59. A body which is to yield but little to a tractile force, must necessarily possess a great index of elasticity. And conversely, the opposite condition necessitates a smaller magnitude. The bones and soft structures of the animal body may explain this antithesis. The former have an index which averages fourteen times that of the tendons, although these belong to the most solid of the soft textures. This difference principally depends on the constitution of the cartilage which forms the basis of bone, and on the numerous salts of lime which it contains.

60. The watery contents greatly contribute to the smallness of the index found for the softer animal tissues. For instance, the fresh tendon of the long flexor of the great toe, had an index of 283·27. But when dried in the open air, it amounted to 412·2.

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61. Few if any parts of our body ever require to extend to twice their length. And on this account, even in very elastic tissues, the limit of perfect elasticity is less than this index. But the latter is inferior to the amount of cohesion; at least in the pieces of aorta above mentioned it was found to be so. The coats of the arteries are, on account of their small index, easily extended, and, after the removal of the weight, quickly return to their previous condition. We shall hereafter see how much more necessary this property is to their function, than an unusual extension of the limit of perfect elasticity. While the function of the blood-vessels demands a high degree of elastic extensibility, the tendons, on the other hand, require to be solid cords, which shall yield as little as possible to the powerful force to which they are exposed. Their average index of elasticity is therefore raised to 360·5, while that of the nerves, which rank next to them, among the tissues formerly mentioned, amounts only to 45·45.

62. The bones may suffice to show what great mechanical advantages result from a proper subdivision of a mass. We have already seen (§ 37) that they possess a greater specific gravity than any of the soft tissues. If their substance had completely filled all the space which they take up, the weight of the skeleton would have been uselessly increased, and the movement of a large part of the animal machinery would have been rendered proportionally more difficult. And hence Nature protects its free surfaces with dense compact tissue, and stows away, in the interior of the skeleton, the marrow, the cavities of which enclose lighter compounds. In this way, substance, weight, and muscular force are all economized; while the other mechanical relations are at the same time improved.

63. Let us suppose the same mass of matter arranged in two different ways,—in one as a dense solid cylinder, and in the other as a hollow one, —it is evident that the latter will offer a larger extent of surface. So that the presence of the medullary cavities of bones produces a greater extent of free surface, which latter may either enclose other tissues, or may afford a multitude of points for the attachments of muscles, tendons, and ligaments. And with this it affords a better provision for many circumstances of solidity, which either generally or exceptionally occur.

64. *Reactive* solidity obtains when a given body is loaded above; *relative* solidity is shown when a weight strives to bend a horizontal and fixed mass. A cylinder which is solid throughout is more unfavourably circumstanced, with respect to both of these, than a hollow one, the moderately thick walls of which contain the same mass of solid matter. Hence it is obvious that the subdivision of the osseous cavity may afford important facilities in this respect.

The proper mixture of cartilage with salts of lime, of compact with cancellated tissue, of rounded with angular forms, of uniformly continuous segments with numerous elevations, depressions, enlargements and

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processes — all this results in making the pieces of the skeleton hard levers, bases of support, and protective textures, such as the artifice of man could never imitate. But even Nature herself is unable always to retain these advantages, or to protect the bones from unusual attacks, as it does many soft parts. A deficient development, such as happens in scrofula, produces curvatures of the bones, and especially of those which have to sustain a heavy weight, such as the vertebral column, the pelvis, and the long and hollow bones of the lower extremities. Hence many of the forms which correspond to the other vital objects, will be either very imperfectly developed, or not at all. Softening of the bones leads to the most extraordinary curves, and, to fractures, on the slightest disturbance. In more advanced life the salts of lime are sometimes too abundantly deposited, and the bones become more brittle than they should be. Their great vascularity, and their chemical constitution, cause them to be more liable to suppuration than many other tissues, such as horn, cartilage, and tendon. Many of them, such as the clavicle, the hollow bones of the trunk, and the extremities, are very liable to be broken. Others, such as the cancellated bodies of the vertebræ, and the bones of the tarsus and carpus, are frequently visited by caries; and others, such as the bones of the nose and palate, are attacked by syphilitic degenerations. The epiphyses and diaphyses of the healthy long bones are so loosely united, that the tibia, for instance, which is suspended from its upper end, and transmits a weight by its lower one, is often torn asunder at one of these points of union by a force which is less than the cohesive energy of its compact substance.

65. The points where many soft tissues are attached exhibit a similar phenomenon. Very strong tendons, such as the tendo Achillis, or thick ligaments, like the great ligament which strengthens the hip-joint, may often be torn away from their attachment to the bones in the dead body, rather than ruptured in their own substance.

66. The active force of a body in movement is the product of its mass multiplied by the square of its velocity. It is therefore increased an hundredfold when the velocity is only ten times multiplied. If the same object be struck by two cannon-balls, one of which has four times the velocity of the other, the latter will penetrate sixteen times deeper. And since the spaces which a body falls through are as the squares of the final velocity, so a body must inflict a greater injury in proportion to the height from which it falls. The construction of many technical varieties of the hammer and the pile-driving machine depend upon the fact, that active force is gained by multiplying the final velocity. For instance, if a mass, the weight of which is unity, falls with a velocity of $5\frac{2}{3}$ feet in a second, its force equals 15·145 times that weight. A hammer which weighs only 9 oz. exercises a force of 12024 oz., when a man, in using it, imparts a final velocity of 638 feet.

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It is thus highly important to estimate the velocity or acquired force of bodies which inflict an injury. But the resistance offered by the different tissues varies greatly. It not unfrequently happens that a bullet which has penetrated the softer tissues goes completely round the ribs, either in consequence of originally wanting the force necessary to break these bones, or from having lost it in a previous part of its course. If the bone has been broken, the velocity with which this has been done exercises an important influence on the nature and extent of the fracture. Since relative solidity diminishes in proportion to increase of length and decrease of thickness, it becomes evident why the long and small cylindrical bones, and the broad and thin flat ones, are most exposed to the danger of fracture, especially where they possess a more brittle layer of compact tissue on their exterior. In this way it often happens that the bones of the extremities are fractured, while the soft parts which encase them preserve their continuity.

67. Gases and vapours have the property of unlimited expansion, so that the space they occupy is only limited by the amount of pressure to which they are exposed. This ability of altering volume in correspondence with pressure, is usually called elasticity of compression; although elasticity, in the strict sense of the word, belongs only to solid bodies.

68. The law of Mariotte teaches us, that the volumes of gases and vapours is inversely as the pressure to which they are exposed. A quantity of gas, which, under the pressure of one atmosphere, or with the barometer at 30 inches of mercury, occupies the space of 1000 cubic inches, takes a bulk of 2000 cubic inches when the barometer is reduced to 15. Regnault has indeed shown that many degrees of heat, and particular amounts of pressure, constitute exceptions to this supposed universal law. But these deviations scarcely affect those physiological phenomena which are connected with the gaseous state. Hence it follows, that the atmospheric gases which are enclosed within our bodies, change their volume or their weight, according to the barometric condition of the atmosphere.

69. Liquids possess a very inconsiderable elasticity of compression. Water at the temperature of its greatest density, or at 38·75°, loses only $\frac{1}{47000000}$th of its bulk on being subjected to the additional pressure of another atmosphere. And in the cases of those parts of our bodies which are saturated with fluids, it is probable that this compressibility is still further diminished. So that we are justified in assuming, that no external or internal forces can modify the condition of these fluids, except by pressing them out, or driving them into other places.

70. We must be careful to distinguish decrease of volume from mere alteration of outward form. However efficiently our bodies resist the first of these, very slight alterations of pressure suffice to produce alter-

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ations of shape, especially in those structures which possess a small index of elasticity. Nature makes use of this to produce many important phenomena.

The blood-corpuscles of the frog (Tab. II., Fig. 23, *a*, *b*), possess large long diameters, and small transverse ones. But even these exceed the width of some of the finer blood-vessels. And just as an elastic ball flattens on striking against an object, and recovers its original rounded form as it rebounds, so these corpuscles become elongated when the stream of the blood drives them into the capillaries, while their subsequent passage into vessels of a larger diameter allows them to return to their original form. We shall subsequently see, that fluids which circulate in small tubes, cling with great tenacity to their surface. But the requirements of nutrition necessitate a change in the contents of the capillaries. The blood-corpuscles, which are in this way forced hither and thither through the finest capillaries, are thus enabled to dislodge, and as it were, to strip off this tenacious peripheric layer of fluid.

71. An essential peculiarity of liquids, is the great mobility of their particles. A pressure which is exerted upon their mass in one point, propagates itself equally in all directions. If we completely fill an elastic bladder with a fluid, it yields to all external mechanical force, in a degree varying with its capacity of resistance; and if its elasticity remains unimpaired, it subsequently returns to its original form. Nature makes use of such an arrangement to constitute the fat of our bodies a kind of self-regulating cushion. Thousands of small vesicles, bounded by elastic walls, enclose masses of oil, which the warmth of the human body prevents from congealing (Tab. II. Fig. 27). The pressure of a body which possesses an extensive surface of contact thus divides itself amongst a great number of small elastic cells, the interstices of which being filled by areolar tissue and nutritional fluid, easily permit these evasive movements.

72. Yielding solid textures moderate the pressure which is transmitted to them from without. In this way the horny cells of the epidermis save us many pains to which we should otherwise be exposed at every step. The sole of the foot, which has to bear the weight of the whole body, is for this reason endued with the greatest number of epidermal cells, especially at those parts which are pressed against the ground in the acts of standing and walking.

73. If a compressing force acts slowly and continuously, the parts so acted upon are extended to the utmost limits of their cohesion. The changes to which most parts are liable in the course of disease, offer striking examples of this. The skin, the nerves, and even the bones, are frequently thus extended to a considerable degree. Physical properties, and the capacity of growth, generally assist in producing these results. The skin covers the most enormous tumours. Particular portions of bone, such as the epiphyses and diaphyses of the cylindrical bones, may

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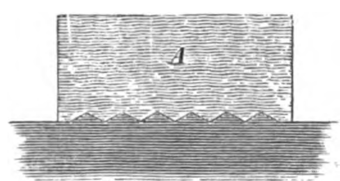
be thus converted into large cavitary shells. And if the cause of such an extension be overcome, the parts often return in a short time to their original form.

74. Here and there Nature allows this distension to go so far that the obstacle offered by cohesion is completely overcome, and the parts tear at the most yielding place. In this way the ovarian follicle of the mammal gradually absorbs extraneous matter, until it finally bursts at the thinnest part, and the ovule which it contains is set free. And although it is as yet undecided whether this phenomenon is merely physical, or whether it depends on a real growth, yet it cannot be doubted that the former cause produces the same results in the progress of disease. Arterial tumours frequently burst solely by reason of a constant increase in the contents of the sac having at last extended it beyond the limits of its cohesion.

75. We know of no body which possesses perfectly uniform surfaces. A highly magnified view of the smoothest solid mass discloses unevennesses, projections and elevations, which are usually irregularly disposed. If we look at this on a larger scale, a solid body (Fig. 3, *A*) grasps, with its projections, the depressions of any other mass, against which it is pressed, either by its own weight, or by external force. If it be moved in the horizontal direction, it must either be raised and depressed in correspondence with these irregularities, or be injured at its surface of contact. Either of these alternatives requires the application of a certain force, which is indicated by the name of the "index or coefficient of friction." The absolute value of this increases directly with the weight of *A*. But the size of the surfaces in contact cannot affect it. So that when one states that the friction of iron upon copper amounts to ·17, this means that an iron cube, moved on a plate of copper, requires the application of 17 lbs. of force for every 100 lbs. of iron. It is, however, perfectly indifferent whether the surface of friction amounts to 1 or 10 square inches.

Fig. 3.



When a sphere is rolled upon a surface, the index of friction determines how much force is lost upon that surface. Other things being equal, this is less than the index of friction first mentioned.

76. As friction forms an obstacle to movement, it furthers the stability of a body. If it were altogether absent, the slightest touch would suffice to produce a displacement; so that it forms a kind of counterpoise, which requires to be overcome in order that movement should be produced. And in point of fact, we find that Nature makes use of both of these relations in various parts of the organism.

77. The deepest layers of epidermis (Tab. II. Fig. 32) are intimately

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and uniformly united; while the superficial horny cells are more loosely connected, and are continually scaling off. Hence the sole of the foot has a very uneven surface, which is of essential use in standing with naked feet. A man in new or ironshod boots easily slips and falls. Felt shoes allow their wearers to walk over ice without falling, where smoother and less yielding coverings would be dangerous.

78. Many internal parts require to be moved to and fro upon others. The movements of the brain and spinal cord, of the abdominal and pelvic viscera, and of the joints and tendons, lead to varieties of gliding and rolling friction. But Nature has here adopted a combination of numerous means, so as greatly to diminish the loss of power which would otherwise result.

79. In mechanical arts we make use of various lubricating substances to overcome the resistance of friction. We cover the surfaces of contact with viscid substances, because these are more efficient than limpid water. They more or less fill up the opposed depressions, and in this way produce a greater smoothness and mobility. And they thus not only diminish friction, but prevent the wearing of the gliding solids. If one piece of oak wood rubs against another the index of friction varies from ·48 to ·34, according as the movement takes the direction of the fibres, or is transverse to them. But if there be water between the two pieces of wood, it sinks from ·34 to ·25. Soap similarly interposed reduces it from ·48 to ·16. The dry friction of cast-iron on oak wood amounts to ·49; but when the opposed surfaces are smeared with hog's lard or oil, it sinks to ·078.

80. If we compare the various organs of our body with the arrangements just mentioned, we find that their surfaces are generally much smoother than those of many polished machines. In addition to this precaution, Nature makes use of albuminous and mucous fluids as means of lubrication. These easily adhere to the surfaces of the organs, and offer very little obstacle to movement. The contents of the various serous sacs and bursæ mucosæ, and the synovial fluid of the joints, thus exert a very important influence in diminishing the impediment which friction affords.

81. The liquid state probably results from the circumstance that cohesion and pressure, *i.e.* the two forces which keep the molecules of matter closely connected together, attain nearly a counterpoise with those of warmth or repulsion, so that the particles become easily moveable upon each other. And if a sufficient obstacle is present to prevent the evasion of a liquid, a pressure in any one direction is transmitted in all others. This fact forms the basis of the laws which regulate the movement and rest of liquids.

Suppose *abcd* (Fig. 4) to be a receiver with unyielding walls, and for the present closed at *c e*. Let it be open above at *a b*, and filled with water

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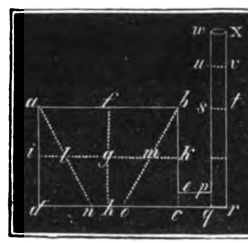
up to this point. The perpendicular and gravitating line of liquid from *f* to *g* presses downwards, with a force corresponding to its specific gravity and its length. But since the pressure exerted at *g* diffuses itself equally in all directions, all of the molecules in the transverse line between *i* and *k* have to sustain the same pressure. And if the line *f g* be prolonged to *h*, the transverse pressure *d c* is of course proportionally increased. It is obvious that the size of this transverse section makes no difference in the result. The hydrostatic pressure of a liquid which remains in equilibrium and at rest, is, therefore, wholly and solely dependent upon the height of the pressure. That is to say, it is measurable by the perpendicular line which may be drawn from the upper to the under surface of the liquid, and which exactly corresponds to the direction of gravitation.

FIG. 4.



Let us now suppose the vessel *a b c d* converted into *a b o n*: it is evident that this can no way affect the hydrostatic pressure, since the height of the column *f h* remains unaltered. Or altering its form to *a l m b*, it would only have the pressure of *f g*, and this, though less than *a n o b* and *a d c b*, is equal to *a i k b*. In one word, the hydrostatic pressure which is exerted at the bottom of any vessel is quite independent of all alterations of its form.

Let us now suppose *a b c d* connected with the long and open tube *q w x r*, by means of *e p q c*. Let it be filled to the same level *s t*, as the water in the larger vessel: it will be in a state of perfect equilibrium and rest. Since the columns *a d* and *f r* have the same height, the same hydrostatic pressure is exercised on the entire transverse section *d r*. And this holds good for all parallel sections up to *a b* and *s t*.

But if *a b* be now shut in by a solid wall, and the fluid in *q w x r* so increased by new additions that its surface rises to *u v*, the additional column *v t* will not only weigh upon *q s t r*, but also upon *a b c d*. And *a b* will have to sustain the increase of pressure, just as much as *s t*. And since the influence is no way dependent on the size of the transverse section, we can in this way produce the most important changes in the large shut receiver by the instrumentality of this small column connected with it.

82. We have already seen that the amount of the hydrostatic pressure depends, not merely on the length of the column, but also on the specific gravity of the liquid. A body, the specific gravity of which is twice as high, will exert twice the hydrostatic pressure of another fluid. The arrangement of the barometer and manometer is based upon this phenomenon; and it has also considerable influence in the movements of the animal fluids.

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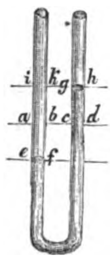
83. If we fill the two perpendicular ends of a bent cylindrical tube with the same liquid it will remain in a state of hydrostatic equilibrium; *i.e.* the two surfaces, one of which is at *ef* (Fig. 5), must lie at the same horizontal level. If we now pour in a quantity of the same fluid corresponding to the cylinder *ikfe*, the equilibrium will in a short time again attain the two surfaces *ab* and *cd*. The fluid on each side is increased to the extent of the column *abfe*, or to half the height of the superadded quantity. But if, on the other hand, we add the same quantity of a liquid which is twice as light, the height of the column in the other limb of the tube would only be raised to half the amount.

FIG. 5.



84. Atmospheric air at 32°, and under the pressure which obtains at the level of the sea, has a specific gravity which is 10467·45 times lighter than mercury. So that a vertical column of air so many inches in length would correspond to 1 inch of mercury. And taking this fluid as our index, we may construct the tube, whose contents shall represent the atmospheric pressure, 10467 times shorter than such a column of air.

85. If we made use of a tube open on both sides, like that just spoken of, the air would press on *ab* and *cd* with equal force, and the quicksilver would have the same height in both limbs of the tube, so that the influence of the air could not be estimated. In order to do this there must be a vacuum over the indicating fluid. The atmospheric pressure will then impel it to a height which will be the exact counterpoise of itself.

This may be better seen by examining the diagram of a barometer given in Fig. 6. The atmosphere presses on the surface of the mercury at *ab*. But since there is no air at *s* to exert a counter-pressure, the quicksilver is maintained in the tube, from *ab* to *s*, as a surplus column which exactly equals the external atmospheric pressure. The same obtains in the ordinary barometer, Fig. 7. The horizontal surface of quicksilver in the shorter limb corresponds to the under surface of the column of quicksilver, which exhibits the pressure of the air. It is thus equal to *ab* in Fig. 6.

Since observation shows that at the sea level the barometer has a height of 29·9 inches, this corresponds to a pressure of 313200 inches of air at a temperature of 32°, and in the same place. Under different temperature and pressure, however, the quantity would be different. Thirty inches of mercury are in this respect equal to about 33 feet of water.

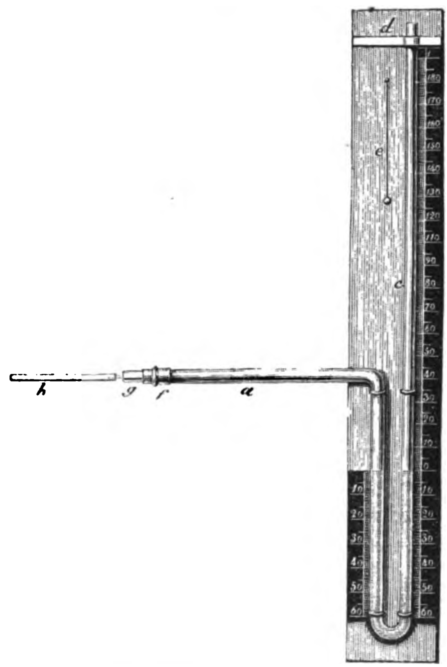
86. A manometer (Fig. 8), which measures the pressure of a liquid, or the force of its stream, consists of a suitably curved tube, fixed perpendicularly, and containing an indicating fluid in a state of equilibrium; *i.e.* re-

acting to the level of 0° in *b* and *c*. If we now allow the entry of another fluid into *b* to compress the indicating liquid, this will experience a de-

FIG. 6.

FIG. 7.

FIG. 8.



pression—suppose of 30°—and a similar elevation will take place in *c*. But in order that the proof liquid thus raised in *c* should maintain its equilibrium without this pressure, *b* must contain so much of this proof liquid as to be not 30° below, but 30° above, 0°. The pressure which we are examining, therefore, amounts to twice 30°, or to 60°. That is to say, the amount to which the proof-liquid falls in one or rises in the other limb of a completely uniform manometer tube, forms the half of the pressure sought for.

The hæmadynamometer is an instrument which in this way estimates the strength of the current of the blood. The pneumamometer is a similar apparatus, which measures the altered tension of the air respired in the act of breathing. For instance, if the hæmadynamometer shows that the blood in the carotid of a dog depresses one limb of the mercurial column 3·15 inches, it follows that the stream in this vessel has a force of 6·3 inches of quicksilver. Water would give nearly fourteen times* as great an estimate, being so much lighter than mercury.

* 13·598.

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Hence when small amounts of pressure are to be estimated this fluid is preferable : thus, for example, it is made use of in examining the current blood of the large venous trunks.

87. In order to reduce the results obtained by one proof liquid to those of a second fluid, we need only multiply the numbers by the quotient of the specific gravities of the first and second fluid. A mercurial pressure of 6·3 inches amounts to 85·68 of water. If we assume the average specific gravity of the blood to be 1·06, a quarter of a line of quicksilver corresponds to ·6547 inches of blood-pressure, and the same amount of water to ·05342 inches.

88. Since every column of fluid acts, with a force corresponding to its height, on every point of the lower surface of the containing vessel, we might find the absolute or total pressure which this has to sustain by multiplying its surface by the height of the liquid, and reducing this cubic capacity to the weight of the fluid, the pressure of which had been previously ascertained. Every square inch of surface which receives the atmospheric pressure at the sea-level and freezing temperature, has 29·9 inches to sustain. Thus we have a total of 29·9 cubic inches of mercury. And since a cubic inch of water weighs 252·6 grains, a cubic inch of mercury will be $252{\cdot}6 \times 13{\cdot}598 = 3460$ grains, so that every square inch exposed to the surface of the atmosphere at the level of the sea, has to sustain a pressure of 14·78 pounds.

89. The outer surface of the author's body, which has a length of 63 inches, and a weight of 119·14 pounds, amounts to about 2325 square inches. So that the atmosphere exerts upon it a total pressure of 34,366 pounds, or 287 times the weight of the body. Quetelet supposes that the outer surface of a very large man measuring 68·11 inches in height, and weighing 167·677 pounds, amounts to 2549·75 square inches. According to this estimate, the total weight would be 37682·7 pounds, or 224 times the weight of the body.

90. This considerable amount of pressure need not surprise us, when we reflect, that it is not only borne by ourselves, but by all the masses which surround us, and that their several degrees of cohesion are only thus preserved. A closer examination of these phenomena will show how the several parts of our organism behave under alterations of these conditions.

91. Since the crust of the earth is separated from the airless realms of space by a girdle of atmosphere, this latter must have its deepest layers more pressed upon, and its higher, less. Omitting all consideration of the exceptions to Mariotte's law, the atmosphere must become denser and heavier, in proportion to the amount of its own mass which it has to sustain. And the condition of the barometer which serves to indicate the several amounts of pressure, will also take cognizance of these states. So that we may make use of this instrument in the measurement of

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heights; *i.e.* may apply it to determine the elevation of any place above the level of the sea.

If the barometer stands at 29·9 inches, the height of the quicksilver column will diminish 1-25th of an inch on making a vertical ascent of 37·73 feet. And if I find that the barometer at Bern has a height of 28·16 inches, I am enabled—apart from all other corrections—to calculate that this place is 1745·4 feet above the level of the sea. The total weight of the atmosphere is thus diminished by more than 1-17th. As the barometer sinks 16·93 inches on the summit of Mont Blanc, this would give a weight of atmosphere corresponding to little more than 2-5ths of that at the level of the sea.

92. If we place a bell-glass on the plate of an air-pump, and completely exhaust it, every square inch of its surface will have to sustain a pressure of nearly 15 lbs. And if its cohesion be not sufficient to resist this weight, it breaks. But if we allow the air to re-enter, while the exterior atmosphere exerts the same pressure, the air contained within its cavity presses from within outwards with equal force. We have, in fact, just the same counterpoise as in the manometer, when both limbs of the tube are allowed to remain open.

A similar condition is present in the human body. While on the one hand the atmospheric column is pressing on its outer surface, it possesses, on the other hand, numerous internal cavities, which are filled with air, and the contents of which exert an opposite pressure with equal force. If this were not the case (apart from the considerations of heat and vapour), our organism would resemble a barometer, or an exhausted bell-glass, and would be perpetually exposed to the pressure of the atmosphere. But as it is constituted, we may rather compare it to a receiver with air playing freely upon both its surfaces.

93. There are certain closed cavities of our body which are filled with liquid, and are so arranged, that the pressure of the air upon them is used as a mechanical force. In this way Nature obtains facilities for the movement of the blood and lymph, which will hereafter be again referred to, as well as for the gliding of tendons and other moveable parts. And an inspection of the serous membranes and joints will teach us what various results may thus be obtained.

94. In Fig. 9, $\epsilon\ \vartheta\ \eta$ are exhibited the air-tight walls of the belly. A fluid, the peritoneal fluid, occupies the peritoneal cavity, and the interstices of the abdominal viscera. The external atmospheric pressure on the walls of the belly fits all its contents exactly to one another. So that any substance remaining under the influence of the pressure of the air can only enter the stomach $q\ r$, and the remainder of the alimentary canal $s\ t\ u\ v$, when driven forward by some additional force. If it passes further, the atmosphere which presses on the whole of the receiving organ, and keeps all its parts in contact, brings together the walls of the

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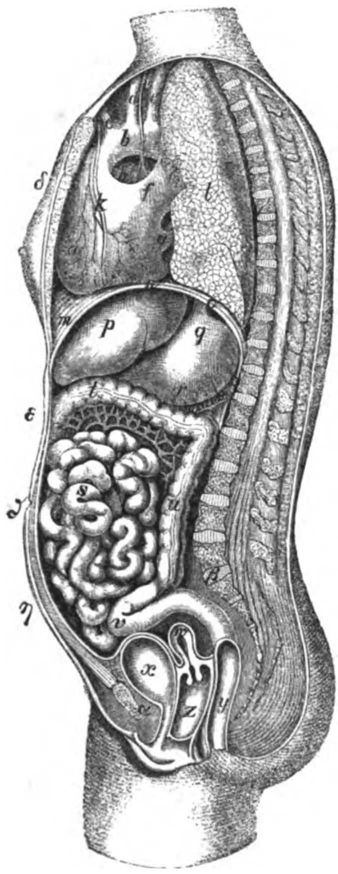
emptied portion. If particular loops of intestine move upon each other, the peritoneal fluid is compressed into the interstices thus formed. If a portion of the contents of the canal is expelled in the shape of fæces, or urine, the external atmospheric pressure again brings the cavity into coaptation with its diminished contents. In short, it enables everything to lie in the smallest possible space, at the same time that it allows the slightest preponderance of pressure to effect changes of space necessary for entering or emerging substances. The same general arrangement is required in the other serous sacs. They contain a liquid, which immediately occupies all the spaces caused by movement or by alteration in the size and situation of their walls. A serous vapour is not present.

FIG. 9.



95. If two hollow hemispheres (*a* and *b*, Fig. 10) be pressed together, and the air which they contain pumped out of them by means of the side tube *c*, and if the entrance of fresh air be prevented by a sudden closure of the stopcock at *c*, we shall find that in all cases where *a* and *b* possess any considerable extent of surface, it will be quite impossible to separate them. Since there is no counter-pressure by air from within, the atmosphere holds the two hemispheres together with a force of 17·48 pounds for every square inch of surface which they possess.

FIG. 10.

96. In the joints a similar arrangement has been brought to the assistance of the muscles. The capsules of the joints form air-tight cavities, which are filled with a certain quantity of liquid synovia, and unite the opposed articular extremities of the bones. Since there is no air in their interior to exert a counterpressure, the head of the femur (Fig. 11, *g*) is retained in the cotyloid cavity, like the hemispheres *a* and *b* when the air is pumped out of them. The accuracy of this conclusion

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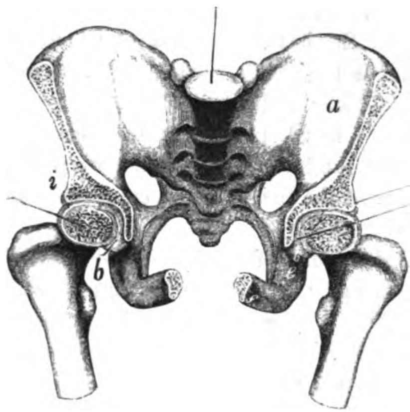
has been experimentally shown by W. and Ed. Weber. They found that on bringing a suitably prepared hip-joint under the receiver of an air-pump, and exhausting the air, the weight of the piece of femur (*b*) caused it to drop out of its socket, while, conversely, the readmission of the air again raised it to its place.

FIG. 11.



97. It is easy to see that this circumstance must cause the articulating surfaces to fit into each other much more accurately than could the capsules and the ligaments alone. Without it the muscles must have borne the additional burden of the weight of the thighbone every time the leg was raised. The air-tight capsule, and the absence of gases and vapours from the interior of the joint, rid it of this useless load; and hence there is less danger of their being fatigued.

98. Many travellers have remarked that, at great elevations, a man suddenly becomes fatigued, moves his legs with difficulty, and is finally either unable to proceed, or is obliged to rest after proceeding a very short distance. Since the atmospheric pressure diminishes considerably in the higher regions, it has been supposed that in such circumstances he is no longer relieved of the entire weight of the leg, but that the muscles are compelled to sustain a part. This affords a very simple explanation of the fatigue just mentioned.

But practised mountaineers have felt none of this embarrassment on the summits of the highest mountains in Europe, such as Mont Blanc, the Jungfrau, and Monte Rosa. And the exertions necessary in climbing a mountain, especially to those unused to them, might readily deceive any one. But, even apart from this, it may be shown, that the greatest height hitherto reached by man allows of sufficient atmospheric pressure to relieve us of the entire weight of the extremities. The hip-joint is that which has proportionably the smallest surface, and the thigh-bone

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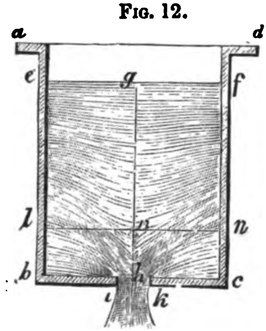
is the heaviest weight: so that if we can verify the above statement for this articulation, it will hold good, *à fortiori*, for the several segments of the arm, and the remaining joints of the leg.

Gay Lussac ascended in a balloon to a height of 7632·2 yards. Omitting all collateral circumstances, this would correspond to a barometric height of 13·46 inches. The severed thigh of a labourer, aged sixty-seven years, who had died accidentally, weighed, with its muscles and vessels, 18·53 pounds. The surface of pressure in the hip-joint amounts to 2·8 square inches. So that the diminished atmospheric pressure would still suffice to remove the weight of the thigh: it would indeed exactly do so ($\frac{13 \cdot 456}{29 \cdot 92} \times 14 \cdot 78 \times 2 \cdot 8055 = 18 \cdot 53$ lbs.).

The right thigh of a new-born male child, when similarly isolated, had a weight of ·5231 lbs., and the hip-joint a surface of ·274 square inches. With the barometer at the height above mentioned, this would sustain a weight of 1·012 lbs.

99. If a liquid flows out of an opening, *i k*, Fig. 12, in the under surface, *b c*, of a vessel, *a, b, c, d*, the amount discharged will depend partly on the velocity with which every molecule of the column *g h* moves, and partly on the number of such columns passing through *i k*. The velocity of the flow and the size of the aperture are therefore the chief conditions to be regarded.

FIG. 12.



100. In hydraulics we distinguish two kinds of velocities, theoretical and real. The first may be immediately deduced from the laws of attraction, or from the general law of gravitation. But the second can only be empirically determined for each particular instance. All that the theory can do is to give certain approximative values.

101. Let us suppose that just so much is continually added above as flows off below. The surface of the liquid, *e f*, Fig. 12, or the height of the column *g h*, will remain unchanged in spite of the exit of fluid below. Now if we confine ourselves to the theoretical velocity of the flow, the theory of Toricelli states, that the molecule *h* comes to the aperture of exit with the self-same velocity which it has attained during its free passage from *g* to *h*. The distance between *g* and *h* forms, as it were, the space through which the molecule falls. But since the final velocities of masses are to each other as the square roots of the different heights through which they fall, it follows that the velocity of exit must have the same proportion. For instance, if the experiment be so managed that the level of the liquid is at first that of *e f*, and then that of *l n*, where *g h* is to *n h* as 4 to 1, it will follow that *h* will have twice the velocity in the former as in the latter case.

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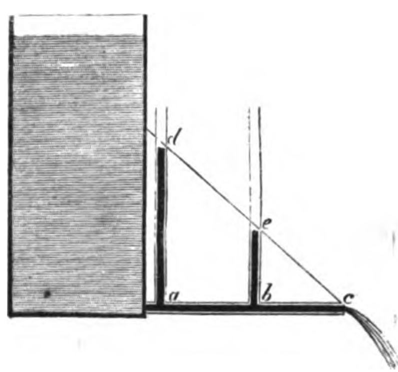
102. It is thus obvious that it is the degree of pressure, $g\,h$ or $n\,h$, which essentially determines the velocity of exit. It is therefore called the index of velocity for a flowing liquid; and every other force which acts upon a fluid mass, may be reduced to a previously defined degree of velocity. It is only necessary to convert it into a column of fluid of corresponding height, which is undergoing a similar exit. Let us suppose that a surface of water, amounting to one square inch, is pressed upon with a force of 1000 grains (996·31 grains, ·14233 lbs.); we may estimate the degree of velocity at 4 (3·9371) inches, since one cubic inch of water weighs 250 grains (252·6 grains, ·03615 lbs.).

103. The form of the aperture of exit, the shape of the stream commencing at this place, the nature, diameter, and course of the tubes through which the fluid mass is driven, and the resistance of the bodies which it meets with on its way; these are the principal circumstances which cause the real to differ from the theoretical velocity.

Their effect is almost always to consume a considerable part of the original force. But they also are reducible to a definite estimate, which is called the degree of resistance. So that the real velocity is that residue of the theoretical which is left after the subtraction of the entire resistance. Hence, in order to get its value we must multiply the theoretical value of the velocities and the quantities discharged by certain fractions, the coefficients or indices of resistance.

FIG. 13.



We may represent the force that propels a fluid through a conducting tube ($a\,c$ Fig. 13) under the form of a neighbouring vessel which contains a column of definite height. The velocity with which the stream rushes out at c must be less than the pressure of the column would alone produce, from two causes. Firstly, the molecules of the water have to overcome the resistance of the atmosphere at c; and in addition to this they are liable to be thrown into various curves. Adhesion to the walls of the tube $a\,b\,c$, and friction against them, constitute a second element of the index of resistance.

All these obstacles obtain when a stream of urine is expelled from the urethra. Its stream is therefore discharged with less force than that which the contraction of the bladder and the assisting abdominal muscles together impress upon it. But on the other hand, that part of the resistance which depends on the passage into a different medium vanishes when

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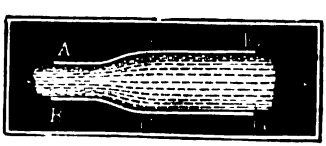
the heart drives the arterial blood into the capillaries. So that here it is only the influence possessed by the walls of the tubes which remains.

104. If we place two side tubes, *a d* and *b e*, perpendicularly in *a* and *b*, the water will ascend in them to a height corresponding with their situation. They are "Piezometers"—*i.e.* they measure the pressure which the fluid exerts at these two points, by the height of the columns they respectively contain. And they thus show how much of the original pressure has been hitherto consumed by the resistance. But the column *b e* must be shorter than *a d*, since the portion of tube between *a* and *b* has added a certain total of obstacles. Applying this to the vessels of our body, we shall find that the different heights simultaneously observed in two hæmadynamometers, whereof one is fixed into a main artery near the heart, and the other into the same vessel further off, will acquaint us with that amount of resistance which is offered by the intervening portion of tube.

105. The detrimental influence thus exerted by the inner surface of the tube depends upon two causes. The peripheric particles of the fluid must strike against the irregularities of the wall. And adhesion tends to retain them in contact. The amount of resistance offered by the first of these causes is as the square of the velocity, while that of the second is simply proportionate to it.* We thus see what important advantages Nature obtains by the extraordinary smoothness of the internal surface of the blood-vessels and absorbents.

106. Leaving for the present the changes produced by the walls of a tube, we may notice that the same quantity of liquid would pass in the same unit of time through any transverse section of an uniform cylindrical tube, *a b c*, Fig. 13. But if we suppose that in its course from A B, Fig. 14, it experiences a dilatation at D C G E, the mass of flowing water will have to diffuse itself over a larger space. If we regard the fluid transmitted in an unit of time as a cylinder which has the transverse section of the tube for its base, and the degree of velocity for its side, the latter will lose just as much as the former gains in extent. So that, other things being equal, the velocity of a fluid is inversely as the size of its channel.

FIG. 14.



* This will be evident if we consider that the shock of these fluid particles against the irregularities will depend upon, 1stly. their number; and, 2ndly, their force. Now, since both number *and* force vary with velocity, the entire resistance of the shock (s) will be $s = v^2$.

So of the next constituent—the quicker the stream, the oftener is the adhesion of each particle overcome,—hence the total adhesion (a) will be $a = v$.

Or, putting both these elements of resistance together, we get $r = v^2 + v$. And if we suppose that the amounts of force and of adhesion specific to the matters made use of are known from experiment, and are indicated by b and c respectively, we may arrange the whole resistance as an equation; $r = bv^2 + cv$.—*Editor.*

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The blood-vessels, the absorbents, the ramifications of the bronchi, and the ducts of many glands, agree in this one circumstance; viz., that the sum of the transverse sections of a number of their subordinate branches is greater than that of their chief trunks. So that the channels widen in the same direction as that in which this subdivision occurs. Therefore the velocity of a fluid which is expelled in the same direction must decrease, while that of one which is coming in the contrary one must increase. In this way, the nearer the blood approaches to the capillaries, the slower is its flow. While in the return of this fluid towards the heart, or in the passage of the lymph onwards, or in the progress of an excreted fluid in ramified ducts of the glands, the velocity of movement is continually increasing. Under similar circumstances, the stream of air in inspiration has a decreasing, and on expiration an increasing, velocity.

107. Those peripheric or most external molecules which suffer from the irregularities and adhesiveness of the internal surface, form a layer which is proportionally thinner, the greater the diameter of the tube.* The resistances offered by very narrow canals to the transit of fluid are thus rendered extremely great.

108. The fine canals with which Nature operates in our bodies, are much more minute than any capillary tubes with which hydraulic experiments have been made. The fluid which is driven through them generally passes into the same medium. But sometimes liquid masses are expelled into the air: the excretory ducts of the sweat glands, and the sebaceous follicles of the skin and external ear, are instances of this.

109. The velocity with which a liquid runs through a capillary tube to pass into another uniform fluid, varies with the nature of the moving fluid. According to Poiseuille, [4]) solutions of saltpetre and acetate of ammonia move more quickly than pure water, while alcohol and blood-serum have a slower rate of movement. When the length of capillary tubes does not exceed a certain proportion to their transverse section, the quantities passing through in a given unit of time are directly as the fourth power of the diameter, and inversely as the length of the tube. It hence results that the resistances are greatly increased by narrowing the tube. The finest capillaries of the body are only 1-11000th of an inch in diameter. Their transverse section is thus 1,210,000 times smaller than that of a capillary tube 1-10th of an inch in diameter. Hence,

* We may, perhaps, explain this statement by rendering it more exact. The areas of circles of different size have the proportions of the squares of their diameters; while the circles themselves are but as these diameters. And it is evident that we may regard the number of molecules contained in a circle as proportionate to its area; while the number of these in contact with the circle will vary with the length of the line forming it. So that an addition to the diameter, which is only multiplied by $3\frac{1}{7}$ to increase the latter number, is involved to a higher power to represent the former one; and thus gives the whole contents a continually increased proportion, or *vice versâ*, as continually decreases the proportionate number of the limitary molecules.—*Editor.*

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under similar circumstances, the quantity of liquid flowing out of it would diminish to $\frac{1}{1,464,100,000,000}$th of that delivered by the larger tube.

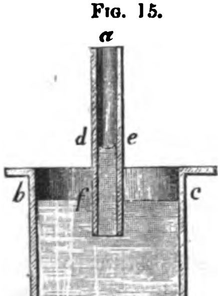
110. Warmth quickens the passage of fluid through minute tubes in a very great degree. The other conditions remaining the same, a capillary tube, which at 39·2° allows one cubic inch to pass through in a given unit of time, at 99·5° permits 2·314 cubic inches to pass. It results from hence, that the higher temperature which is offered by the warm-blooded animals may, in this respect, be of great advantage. And it also explains why the flow of blood in the cutaneous capillaries is retarded, or even altogether checked, when the temperature of the skin is considerably lowered by the application of cold.

111. When a fluid passes through a capillary tube, a peripheric layer is formed, in which the particles have a much slower stream than those of the middle. This is often called the immovable layer. Its power necessarily increases with the magnitude of the resistances offered by the inner surface of the wall. We shall hereafter see that this obtains even in the finest capillaries of our body: although to a much less extent than in glass tubes with a larger transverse section—a fact which is a fresh instance of the way in which Nature avoids all unnecessary loss of power.

112. The powerful influence possessed by the phenomena of adhesion in minute intervals of space leads to numerous peculiarities which receive the collective name of capillary attraction. Since all organized parts are porous, we meet with these phenomena in every organ of the body. And most of the conditions which determine the metamorphosis of matter are intimately connected with them.

113. If we dip a capillary tube (*a*, Fig. 15), the inner surface of which is moistened with the same fluid, into water, a watery solution, alcohol, ether, or oil, we find that it fills, not only up to the level of the surrounding fluid, *b c*, but even higher, to *d e*. This surplus of elevation, *d f*, is called the capillary height.

FIG. 15.



114. If a liquid is contained in a large receiver, its upper surface forms a plane, which is at right angles to all the columns of fluid descending in the direction of gravity. Hence it appears to us in the shape of a horizontal surface, while, contrary to this, the level *d e*, (Fig. 15) is excavated. Its greatest elevation is at the margin, and its least is in the middle.

115. If a solid and a fluid body are in a state of mutual adhesion or "prosaphy," the latter seeks to moisten the former to an indefinite extent. The cohesion or "synaphy" of the fluid,—*i.e.* the force with which its molecules mutually attract each other,—opposes itself to this attempt

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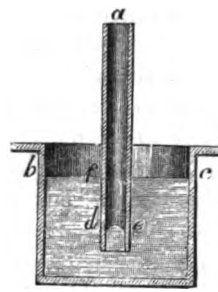
Both these operations counteract each other in the capillary tube. And the excavated surface constitutes a visible expression of this antagonism.

116. If we select a fluid which has no adhesion for the wall of the tube, or which will not moisten it, we shall obtain phenomena exactly the reverse of the preceding. If we plunge the same capillary tube (*a*, Fig. 16) into quicksilver, or any other melted metal, the level, *d e*, of the fluid contained in it does not rise to the height of *b c*. It remains at *d f*, below this. So that we have a capillary repulsion, instead of a capillary attraction. At the same time the form of *d e* is convex; so that the highest point of its curve occupies the middle of the tube.

FIG. 16.



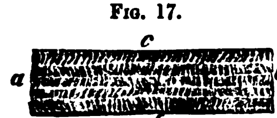
117. If the walls of the capillary tube consist of inorganic matter, their nature exercises no influence on the capillary height, *d f*. Thus water rises equally in glass or metallic tubes.

118. But if the inner surface of the tube has been covered with an uninterrupted layer of fat, the water is repelled. While if it can penetrate the fatty mass, and so moisten the tube, the increase of height reappears.

The elevations of adhesive, and the depressions of non-adhesive, fluids are inversely as the size of the tubes made use of. But they also vary considerably with the nature of the fluid applied. Thus with a tube of 1-25th of an inch in diameter, and a temperature of 39·2°, water rises ·608, olive oil ·296, and ether ·208 inches. These quantities diminish at an increased temperature. Adopting the empirical formula proposed by Brunner,[5]) the fluids just named rise ·5708, ·283, ·1613 inches at a temperature of 98·6°.

119. We may regard every part of an organ as a mass which is traversed by interstices in all possible directions, as shown in the diagram, Fig. 17. This structure gives the aggregate tissues the power of absorbing fluids when dry. When a liquid body presses on *c*, while an elastic one is present at *d*, it also renders them capable of serving as a filter. And finally, when two fluids with proper action on each other are subject to its influence at *c* and *d*, it gives rise to diffusion.

FIG. 17.



120. When a portion of dry animal matter is placed in a fluid which is capable of moistening it, the latter gradually penetrates its interstices; and the whole increases in size and weight. The amount of this absorption or imbibition depends upon the nature of the organized body, and of the fluid; together with the temperature, the pressure, and the duration of the operation. But hitherto there have been no experiments which

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would enable us to reduce the influence of these numerous elements to definite laws. For even assuming the volumes hitherto determined to be accurate, they offer but an approximative value; since adhesion allows layers of fluid—which do not belong to the question—to attach themselves to the moistened side. Nevertheless they plainly show how greatly the result depends on the nature of the fluid.

121. According to Chevreul 3½ ounces of tendon took up, in the course of twenty-four hours, 10·86 cubic inches of water, 6·96 of salt-water, and 5·25 of oil. Similar experiments by Liebig have shown that alcohol is about midway between a solution of salt and oil. The nature of these fluid compounds renders these differences sufficiently explicable. The small amount of oil depends on the low degree of attraction which this fluid possesses for the animal tissues. Alcohol exhibits the same circumstance, and would in addition rather shrink up than expand the mass. Watery solutions are inferior to pure water, since a certain amount of the attractive force is expended in the process of solution. Besides this, we ought not in these cases to forget that many fluids—such as pure water, all incompletely saturated solutions, and alcohol—not only penetrate the interstices of the organized mass, but can chemically take up some of its constituents, and essentially change others.

122. Under ordinary circumstances our skin is dry. But when brought into contact with a liquid by bathing, it gradually becomes saturated. In particular places, the fatty particles of the cutaneous secretion oppose themselves to the imbibition of the water. And the air is often obstinately retained in the small interstices between the skin and the larger or smaller hairs. But if these obstructing substances are dislodged, the integument becomes more and more saturated. It loses that capacity of resistance which it ordinarily possesses, and which is so necessary to the sense of touch; and the fluid is not only imbibed by the interstices of the horny cells, but also softens their substance.

123. A filter is a porous partition, which first absorbs the liquid constituents of the fluid submitted to it. The pressure exercised by the numerous strata of the mixture then drives the fluid through the pores, as through a system of fine tubes. The difficulty of the transit increases with its length, and is also especially augmented by the fineness of the pores. The better kinds of filtering paper are, therefore, very thin. They thus form shorter and more simply subdivided canals. The particles of fluid, which have been pressed through, aggregate into drops on its free side of the filter; and when gravity preponderates over cohesion, these drops finally fall.

124. Delicate animal membranes, such as the pleura, the peritoneum, or the other serous coverings, make excellent filters. The corpuscles of milk, which will pass through even good filtering-paper, are retained on these membranes. Very considerable amounts of pressure may not only

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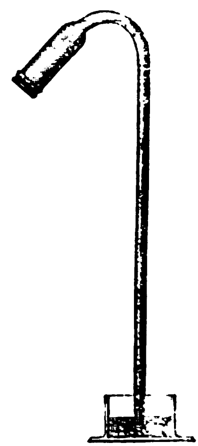
increase the rapidity of transudation, but can also extend the skin itself; and by thus enlarging its interstices may allow thicker fluids to pass through, which would otherwise be incapable of doing so. The albumen of an albuminous solution, or of the serum of the blood, is unable to pass with the pressure of a column of small height. But if the pressure be increased it soon transudes.

125. The evaporation which takes place through porous partitions constitutes a kind of inverted filtration. If a bent tube filled with a watery fluid be shut by an organized membrane, (Fig. 18) the mercury which limits it below will gradually ascend in the tube. The membrane becomes first soaked through with fluid. The most external particles, which are in contact with the atmosphere, gradually evaporate according to the pressure, temperature, and hygrometric condition, of the air. Other fluid necessarily takes its place. The uninterrupted continuance of this process diminishes the mass of fluid enclosed in the tube, and therefore the space which it fills. The pressure of the external air operating unchecked on the surface of the mercury, drives it up the tube as far as the tension of its contents will allow. It is obvious that such an apparatus may be used to measure the results of evaporation.

FIG 18.



The free surfaces of plants and animals, which give off water and other combinations in the form of vapours, must permit of similar indirect results. Unimpeded counter-pressure will force up compensating fluids.

126. It is quite unnecessary that the liquid mass should be in immediate contact with the organized partition. If it can evaporate at the existing pressure and temperature, it saturates with its vapour the space of air above. And this vapour again transudes the organized partition to become free as soon as the exterior atmosphere has also become saturated in less degree. Hence the fluid undergoes a continual diminution. If we partially fill a glass with water, and exactly close its aperture by an animal membrane, we shall find that, in spite of this, the height of the fluid gradually decreases.

127. The results of this experiment are essentially determined by the affinity which the vapour has for the isolating texture. If we use a pig's bladder and a mixture of alcohol and water, the alcohol gradually becomes more concentrated, because the pores of the membrane attract and transmit more watery than alcoholic vapour. And from a similar reason, if we exchange the bladder for a thin sheet of india-rubber, the reverse obtains.

128. If the interstices of a porous body imbibe a fluid of any kind, it will probably be to a certain extent condensed when it is in immediate

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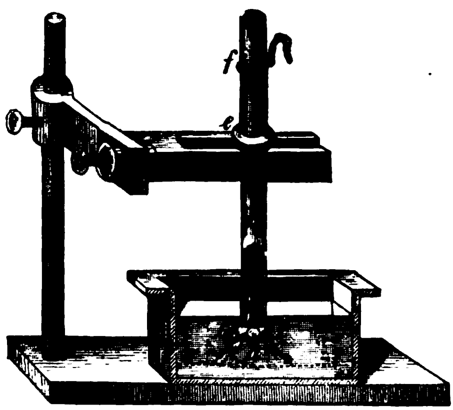
contact with solid walls. And if it contains solid matters in solution these may be in great proportion kept back during the filtration. A solution of salt which Matteucci conducted through 26 feet of sand was found to have lost 1-10th of its previous specific gravity.

129. If we fill a vessel with water (*a*, Fig. 19) and plunge into it a tube, which is shut below by a porous partition *b c*, and is filled to a certain height, *d*, with a saline solution, a diffusion of the two fluids will

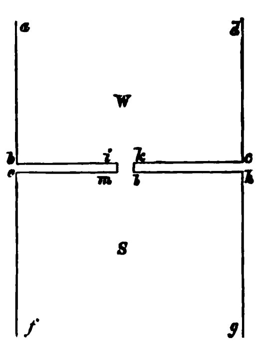
FIG. 19.



be produced. The pores of *b c* allow the molecules of the dissolved solid to pass from *d* to *a*, and those of the water to pass from *a* to *d*. The current from without inwards (indicated by the clear arrow) is called *endosmose*, and that in the opposite direction, *exosmose*.

130. With the aid of the accompanying diagram (Fig. 20), the causes and chief conditions of the phenomena may be very clearly and simply shown. The two cavities *a b c d* and *e f g h* are filled with the fluids *W* and *S*, which are separated from each other by means of the porous partition *b c h e*. The aperture of communication, *i k l m*, corresponds with one of the interstitial openings which produce the diffusion. If *W* were water and *S* oil, no change would occur without the aid of unusual forces;—whether *i k l m* were filled with the former or the latter of these fluids. The atoms of the fluids on either side would have no mutual attraction. The fundamental condition of endosmose consists in the affinity of the fluids which are separated by the porous partition. Hence we say that it is only miscible fluids which are susceptible of diffusion. And

FIG. 20.



since the membranes of the living animal are soaked with water, unless under special adjuvant circumstances, oils will be rejected.

131. If we exchange the water, *W*, for a solution of soda or potash, diffusion is rendered possible by saponification. And since the blood-vessels and absorbents of the human body inclose the alkaline lymph and blood, they exhibit conditions which are more favourable to the taking up of fat than if they contained pure water.

132. When fluids are driven through by a mechanical force which we can express as a determinate amount of pressure, the resistance is vastly increased by a diminution in the diameter of the conducting tubes (§ 109). If *i k*, Fig. 20, is but small, the influence which differences of hydrostatic pressure would exert on the two fluids may be disregarded as inappreciable. Under such circumstances the phenomena of diffusion are therefore independent of hydrostatic influences. But if, on the other hand, one fluid can exert a much stronger pressure than the other, this causes the organized membrane to yield, to acquire larger pores, and thus to offer fewer obstacles to transudation. So that not only diffusion but filtration occurs.

133. The behaviour of the partition in this respect, the form, size, and subdivision of its interstices, and the attraction which the walls *i m* and *k l* exert on the fluid which they contain—all these circumstances are liable to great variation. And they not only differ in different animal membranes, but also in different portions of the same bladder or other part. It is often not indifferent which side of a membrane is in contact with a particular fluid. And since these circumstances influence the strength and rapidity of diffusion, it follows that in separating the same fluids by unequal membranes we are instituting different kinds of experiments. The manifold character of the partitions which are used to transmit the fluid compounds of our bodies allows of an infinite variety of diffusive results. And since porosity is capable of being affected by the influence of the nerves and other circumstances, one and the same membrane may, at different times, produce very different results.

134. Let us suppose the partition, *b c h e*, to have been originally moistened with water, so that *i k l m* enclosed a column of that liquid. Let *W* be also water, and *S* a solution of salt. In this case a transverse section made at *i k* would not meet with any foreign fluid; while at *l m* it would intersect the saline solution;—a body of greater density, in which mutual attraction holds together a certain number of atoms of salt and water. Limiting our attention to this intermediate column of water, we shall find that it seeks to equalize the difference of density between *i k* and *l m*, so that its mass may contain an uniformly divided quantity of saline molecules. Molecules of salt must therefore undergo an endosmose in the direction *l k*, from *S* towards *W*; and *vice versâ*, particles of water pass outwards by exosmose in *k l* from *W* towards *S*. But when *i k l m*

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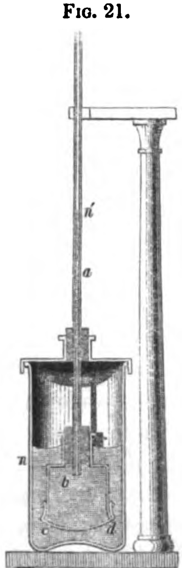
has begun to take up saline particles, the struggle for equality is repeated at both its surfaces, *i k* and *l m*. *W* takes up salt, and somewhat increases its density, while *S* is diluted with water. If no obstacle intervenes, the diffusion only ceases when the atoms of water and of salt are equally divided amongst all parts of both fluids; *i.e.* when both of these exhibit the same density or specific gravity.

135. The number of saline particles which pass over from *S* through *i k l m* towards *W*, and the number of watery particles which take the reverse path during the same period of time, will vary with the nature of the substances dissolved in *S*. Other circumstances remaining unaltered, there are about four units of water to one of salt, and twelve of water to one of sulphate of soda. Jolly, [6]) who first drew attention to these proportions, named them the endosmotic equivalents of the particular bodies.

136. Since these results are so variously affected by the density of the solution, by the nature of the membrane, and by temperature and pressure, it is not difficult to explain why different endosmotic equivalents have been obtained from a series of different experiments made with two similar fluids. If it were possible to reduce all but one of these conditions to an exact equality, the differences in the endosmotic equivalents would permit a more exact investigation of this remaining one.

137. The phenomena of diffusion have been investigated in two ways —by volume and by weight. Here, as in most other cases, the use of the balance is greatly to be preferred, since the determination of space is open to many errors which are scarcely to be avoided, and often not to be remedied.

FIG. 21.



138. Fig. 21 exhibits the endosmometer first used by Dutrochet, which gives at least an approximation to the changes in the volume of the diffused fluids. A vessel (*b*, Fig. 21) which contains one of the fluids, and is shut below by the porous membrane *c d*, is connected above with a tube, *a*. This is fixed vertically, and is plunged to a certain depth into the second fluid, *n*. If *b* is originally a solution of salt, and *n* pure water, the former is gradually diluted and increased in volume. If the saline solution at first stood on the same level with *n*, it rises in course of time towards *n'*; while the surface of *n* is depressed. And by means of a scale the rise of the fluid in the ascending tube *a* may be followed numerically. If the capacity of *b* is also known, the increased bulk of the saline solution may be easily estimated.

This arrangement has the disadvantage, that the hydrostatic pressure upon the membrane *b c* becomes greater, the more *n* rises in the tube. On

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this account, Vierordt [7]) constructed an endosmometer in which this is somewhat provided against. If we determine the interchange of fluids by the alteration of weight instead of size, we may constantly depress the inner tube in the course of the experiment, so that no considerable excess of pressure can ever occur. The error which evaporation allows of is best avoided by making air-tight the vessel whose contents diminish in volume, and closing the other one with two layers of asbestos and sulphuric acid. The first, which receives the vapours of the endosmotic fluid, may be weighed with it; but the second, which is to guard against the evaporation of the air, must be removed before every weighing.[8]

139. Supposing *d*, Fig. 22, to be a saturated solution of salt, and *a* distilled water, the diffusion will continue until the densities of *a* and *d* are as nearly identical as collateral circumstances will permit. If the quantity of *d* be only a small fraction of *a*, still *a* and *d* will contain more or less considerable per-centages of salt; while, on the other hand, if *d* is originally very small, or *a* very large, we get at last so weak a solution of salt in both vessels that we may almost disregard the per-centage of solid matter, and consider the fluid contained in *d* as distilled water. And if *a* be repeatedly filled up with pure water, the like will happen, even when its quantity is much less considerable.

Jolly made use of this method to determine the endosmotic equivalents. If the tube shut by *b c* contains a certain quantity of a soluble solid, or a solution of the same, while the distilled water *a* is frequently changed, the resulting fluid finally becomes so dilute that it may be fairly regarded as pure water. The proportion of the weight of solid matter originally present to that of the fluid which has entered gives the endosmotic equivalent.

Thus, for instance, when the inner tube originally contained 37 grains of dry salt, it showed at the end of the experiment 142·95 grains of water. Hence the endosmotic equivalent here amounted to 3·99. If a solution of salt had been used containing 15·4 grains of salt and 46·33 grains of water, under similar circumstances 107·646 grains of water would have been finally present.

140. If we arrange in a series the endosmotic equivalents, as obtained by Jolly by means of a pig's bladder prepared with alcohol, they will be as follows:—

Substance.	Endosmotic Equivalent.	Substance.	Endosmotic Equivalent.
Hydrated Sulphuric Acid . . .	·308 to ·391	Sulphate of the Oxide of Copper . .	9·564
Bisulphate of Potash	2·345	Gum	11·79?
Salt	·820 to 4·58	Sulphate of Soda . .	11·033 to 12·44
Alcohol	4·140 to 4·336	Sulphate of Magnesia	11·503 to 11·802
Sugar	7·064 to 7·25	Sulphate of Potash .	11·42 to 12·76
		Hydrate of Potash .	200·09 to 231·4

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Consequently the equivalent of hydrate of sulphuric acid is on an average 617 times as small as that of hydrate of potash.

141. We have already seen how the ascent of water, ether, and oil diminishes under the influence of a higher temperature; while on the other hand, it increases the amounts passing through a capillary tube. The latter phenomenon is more connected with adhesion, the former with cohesion. It had been previously remarked, that under higher temperatures endosmose was increased. Jolly found that the endosmotic equivalent increased with increased temperature. Glaubersalt had an equivalent of 11·07 at 42·08°, and of 19·53 at 80·6°. Common salt showed the reverse of this: its equivalent was 4·43 at 32°·45 and 4·12 at 53°·15.

142. We may easily assume that, other things being equal, the quantities of substances transferred within a definite time correspond to the difference in the densities of the two fluids. But since the longer the diffusion lasts, the closer becomes their equality, it follows that the same unit of time effects a less change of weight at a later than at an earlier period. Hence it follows, that the rapidity of endosmose increases with the difference in density, and is therefore greatest at the commencement of the process.

In a series of experiments, Vierordt 9) allowed 6·103 cubic inches of a saline solution of different degrees of density to act upon 6·103 cubic inches of water, through 2 square inches of bladder: and examined the bulk five hours after the commencement of diffusion. Where the 6·103 cubic inches had contained half an ounce of salt, the water had lost ·214 cubic inches. When the original quantity of salt was 1·066 ounces, it had lost ·32894 cubic inches.

Although the temperature in both cases amounted to 50°, the more concentrated saline solution exhibited a lesser decrease of the water opposed to it, and consequently a smaller increase of its own volume.

Since there are here only 6·103 cubic inches of water opposed to the same quantity of saline solution, they must take up more salt from the dense than from the dilute fluid in this long space of time. So that the process of equalization is at first to a certain extent accelerated for the concentrated mixture. But since the changes continually diminish as the period of equalization approaches, the more concentrated solution is then placed at a disadvantage compared with the more dilute one.

143. Tenacious fluids may, under circumstances otherwise identical, form a temporary or permanent hindrance to diffusion. A solution of albumen, when mixed with intestinal mucus, takes up less water. According to Vierordt, a saline solution containing 5·242 ounces of gum, and having a bulk of 6·1 cubic inches, increases one-fourth less than when the viscous mixture is not present. Similar differences affect the initial rapidity of endosmose. Bruecke separated water and a solution of albumen, or serum of the blood, by the shell membrane of the egg. He

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found that the salt first passed through, with a small quantity of organic matter; while the albumen came later. Similar phenomena are seen in the secretions of the living body.

144. When an animal membrane is extended by a considerable hydrostatic pressure, diffusion is facilitated in three ways. The active surface is increased, as well as the diameter of the interstices, while new pores are here and there produced. Hence under such circumstances, albumen transudes in much greater quantity to gain the water on the other side. And tenacious mixtures, which from the smallness of the interstices were hitherto altogether retained, can now take part in the diffusive currents.

145. When two different solutions are separated by a porous partition, a chemical attraction is added to the other causes of this mutual operation. If a precipitate be formed, it may fill the interstices, so as first to diminish diffusion, and then altogether to prevent it. If the pores are filled with a mass which can only be expelled with difficulty or not at all, similar effects are produced.

146. Even if thicker membranes be made use of, such as the coats of the small intestine, the aorta, or the inferior cava, still the first endosmotic fluid transudes in a very short time. A solution of prussiate of potash, which diffuses itself with a solution of chloride of iron, requires less than a second to pass through the mucous membrane of the small intestine and its ordinary fluid (amounting to ·059 inch), under a pressure of ·063 inch of mercury. And if the pressure be increased to from 1·18 to 1·57 inch of mercury, the time occupied is so short as to be quite inappreciable. So that in the living tissues diffusion is almost instantaneous when the necessary conditions are present.

It may be approximatively estimated, that the first interchange of matter effected by the walls of the capillaries of our body occurs in 1-300th to 1-800th of a second, at a pressure of only ·05532 inch of mercury.

147. If we connect a blood-vessel *a* (Fig. 22), with a funnel *b*, and allow a fluid continually to flow towards *e*, while the surrounding mixture remains at rest, the phenomena of diffusion must be greatly facilitated. For at every instant, fresh particles of the fluid in *a* are brought into mutual action with *d*. The difference of density will be maintained at a higher point than if the fluid in *a* were at rest. The diffusion is thus increased, especially when the duration of time necessary to the mutual action of the fluids is less than the velocity with which the molecules of one of them pass. It is hence evident, that the movement of the blood is of great use in the phenomena of the interchange of matter now under consideration.

148. When the molecules of a fluid transude a porous partition, it is by no means a matter of indifference whether they pass in the vaporous

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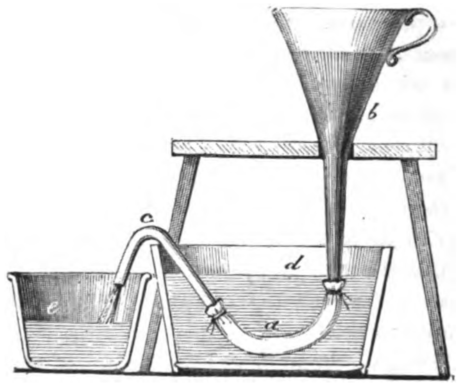
or liquid form. The same membrane may behave very differently in the two cases. Thus our integuments, in their ordinary state of dryness, allow an easy transit to watery vapour in large quantity; while liquid water is altogether prevented from passing.

FIG. 22.



149. Under equal pressure, two dry gases, which are chemically indifferent to each other, and separated by a porous substance, are exchanged in inverse proportion to the square roots of their densities. This law of the diffusion of gases, which may be theoretically deduced from the movement of fluids, is named Graham's law, he having originally proved it by experiment.

Taking the density of the atmosphere at 29·92 inches barometer, and 32°, as unity, the specific gravity of oxygen is 1·10563, and that of carbonic acid 1·5291. When these two gases diffuse themselves under the circumstances mentioned above, ·85 volumes of carbonic acid are exchanged with 1· of oxygen. Thus the vessel containing carbonic acid receives 3-20ths more oxygen than it gives off carbonic acid.

150. Porous solid bodies and liquid masses can take up part of the air in contact with them quite independently of any chemical affinity. Other circumstances being equal, the quantities thus taken up vary with the nature of the absorbing and absorbed substances. Every liquid possesses a specific capacity of absorption for any given gas.

For instance, one volume of water takes up ·05 volumes or a twentieth of its bulk of atmospheric air. And when deprived of this air, it absorbs ·042 volumes of nitrogen, ·065 of oxygen, and 1·06 of carbonic acid, or 43·78 of sulphurous acid gas.

One volume of alcohol absorbs 2·60 volumes of air, one volume of ether, 2·17. A volume of a nearly saturated solution of salt only takes up ·329, and a volume of solution of chloride of calcium only ·261, volumes.

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151. If a number of gases be presented to one fluid, each is absorbed in a different proportion to that in which it would be taken up if alone. One volume of water at 64·4° was exposed to 3·90 volumes of a mixture of equal bulks of oxygen and carbonic acid: it took up ·471 volumes of the latter, and only ·05 volumes of the former gas.

152. So long as other circumstances, and especially those of temperature, remain the same, pressure exerts no influence on the volumes of the different gases taken up by any particular fluid. One volume of water always absorbs ·065 volumes of oxygen, whether the external pressure amounts to 29·92 or 14·96 inches. Omitting the exceptions to Mariotte's law already mentioned (§ 68), the weight of a definite volume of a gas increases in direct proportion to the pressure exerted upon it. So that the weight of the quantity of gas absorbed will increase or decrease with its tension. If 61 cubic inches of water take up 3·9668 cubic inches of oxygen, this bulk, which at 29·92 in. barometer, and 32°, weighs 1·4363 grains, at 14·96 in. barometer, or half the pressure, weighs but ·718 grains, or is only half the quantity.

153. The Daltonian theory rests upon this law laid down by Henry, and upon another proposition which is derived from the laws of vapour, and will be considered hereafter. Let us suppose a space of 6·103 cubic inches to be filled with atmospheric air, which contains 21 volumes per cent. of oxygen, and 79 of nitrogen. Each of these gases is exposed to a pressure of 29·92 in. barometer, or a single atmosphere; therefore each has the tension which it would possess as the sole occupant of this space. If the 1·28 cubic inches occupied 6·103, their tension would sink from 1· to ·21 atmospheres, and similarly that of the nitrogen would be ·79.

If the temperature remain unchanged, every fluid will absorb the same volume under all pressures, and Dalton supposes that this equally obtains with each gas of a mixture. But we must calculate its tension as though it occupied the entire space; and make this estimate at the end of the process of absorption.

These conditions are best obtained by exposing to the atmosphere a vessel filled with water which has been deprived of all air; since the quantities of nitrogen and oxygen absorbed remain utterly inconsiderable in comparison with those contained in the whole atmosphere. Hence neither the bulk nor the pressure of the gases experience the slightest change during the course of absorption.

If we had exposed one volume of water free from air to pure oxygen, it would have absorbed ·065 volumes under the pressure of one atmosphere. If it be exposed to air it absorbs just as much oxygen, with the difference, that this has a tension, not of 1·, but of ·21. If we reduce this to a pressure of one atmosphere we get $\cdot065 \times \cdot21 = \cdot01365$. Since one volume of water would take up ·042 nitrogen, if this alone were present,

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we get $\cdot042 \times \cdot79 = \cdot03318$. Hence one volume of water absorbs a total of ·04683 volumes of air, composed of ·01365 volumes of oxygen, and ·03318 volumes of nitrogen (§ 150).

154. If this experiment be repeated in a closed vessel, the circumstances vary at every instant. Since the water takes up unequal quantities of the two gases, either their volumes become altered during the time of absorption, or supposing that this is artificially prevented, their tension is affected. Hence a better method of estimation must be introduced.

155. Keeping to the Daltonian hypothesis, that one gas has no influence on the pressure of another, and may therefore be regarded as a vacuum in this respect, we may easily determine the exchange which takes place between a liquid containing a certain gas and a space of air.

We will suppose a non-oxidizable liquid, saturated with carbonic acid, to be exposed to the atmosphere, which we will assume to be devoid of this gas :—the carbonic acid contained in the liquid will behave just as if the space above it were a vacuum. It will continue to diffuse itself into the air, until the tension of the quantity there present equals that portion of it which is retained by the liquid. And *vice versâ*, the oxygen of the air is absorbed just as if it alone had been present, and had divided itself over the whole of this limited space. The behaviour of the nitrogen depends on exactly the same causes. And if a given volume of air be used in the operation, a more careful theoretical consideration will show, that its proportion to the volume of the liquid must also be considered.

The Daltonian theory has not yet been fully corroborated by experiment. Many phenomena, such as for instance the aeriform contents of snow-water, are rather against than for it. The experiments made upon the proportionate absorption of gases depend almost solely upon older and more insecure methods of Eudiometry, the results of which do not offer the delicacy requisite for a satisfactory proof of this theory. On the whole it is probable that the main laws enunciated by Dalton approximate to the truth. But it is not unlikely that their elementary conditions differ from those which his theory would suppose.

Since the blood which circulates in the blood-vessels of the lungs gives off carbonic acid and very small quantities of nitrogen, it is evident that porous membranes, which separate a liquid from a space filled with air, must allow of an interchange of gases. But more accurate physical research fails us. It is therefore impossible even to theorize on the details of the result.

156. The vibrations of elastic bodies play an important part in the vital functions of the organism. The perception of such a change constitutes the function of the two highest organs of sense. The eye perceives the undulations of the luminous æther; and the ear those of ponderable matter, whether fluid or solid. Since we shall hereafter examine in

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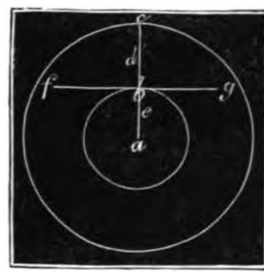
detail into the functions of these organs, we need here only acquaint ourselves with the general relations of the tissues of our bodies to LIGHT.

157. When a molecule, *a*, Fig. 24, of a substance which is uniformly elastic in all directions, falls into a state of vibration, the disturbance is propagated equally on all sides. Circular waves are produced, as shown at Fig. 24. This is best seen by looking at a surface of stagnant water, into which a stone has been cast. Any radius whatever—for instance,

FIG. 23.

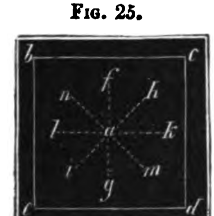
FIG. 24.



a c, Fig. 24,—which is drawn from the centre, *a*, to any point of the circle or sphere around it, forms a ray of undulation. The time necessary to communicate the disturbance from one molecule to another along a ray of given length, from *a* to *b* or *c*, constitutes the velocity of propagation. Taking an unit of a second of time, this velocity amounts to 928 millions of feet for light, and to 13071 feet for atmospheric air at 32°.

158. In considering the kinds of vibrations recognized by the eye and the ear, we find an essential difference. If a molecule, *b*, Fig. 25, be disturbed, it may possibly move to and fro in all imaginable planes. But, according to Fresnel, the impression of light depends solely on those vibrations which occur at right angles to the direction of swift propagation, *a c*, or in the transverse plane, *f g*. Sounds depend on exactly the reverse circumstances: they proceed from the molecular movements which correspond to the vertical longitudinal plane. Hence we see the transverse vibrations of the particles of the luminous ether, and hear the longitudinal ones of ponderable elastic substances.

FIG. 25.



159. Supposing *b c d e*, Fig. 25, to represent a part of the transverse plane, *f g*, Fig. 24, the luminous molecule, *a*, may vibrate in all possible directions, *f g*, *h i*, *k l*. In ordinary light, this uncertainty, and the change of path thus permitted, really obtains. But on the other hand, polarized light has a predetermined, fixed, and one-sided course. If it be rectilineally polarized, *a* vibrates in only one definite path; for instance, in *f g*. This *f g* is therefore the projection of that transverse plane of vibration possessed

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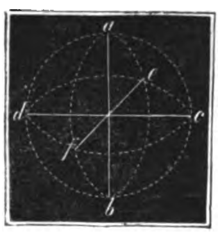
by those particles of the æther which occupy the plane of polarization, *k l*. But besides a rectilineal, there is a circular and an elliptical polarization: the names of which sufficiently indicate the difference in their modes of vibration.

160. We have hitherto assumed that the vibrating luminous æther is equally elastic in all directions. And this is certainly true of those bodies which refract light simply. But on the other hand, there are bodies which possess a power of double refraction, so that the elasticity of the luminous æther which they contain varies with the three different dimensions of space.

We may best depict this fact by representing the degree of elasticity in any given dimension as a line, which may be named the axis of elasticity. We get, in all, three such axes; one (Fig. 26), *a b*, from before backwards; one, *c d*, transverse to this from right to left; and a third, *e f*, which is perpendicular to both, and passes from above downwards. These lines, *a b*, *c d*, *e f*, have equal lengths in all simply refractive substances, such as air, water, or common glass. But if this is not the case, we get a doubly refractive body. In such circumstances, one of two things may occur. Two of the axes of elasticity—for instance, *a b* and *c d*—are alike, while the third is different: or all three may exhibit different lengths. The first case obtains in bodies which have one axis of double refraction: and the second in those which have two such axes. Calcareous spar and phosphate of lime are optically uniaxial; while mica, sulphate of lime, potassio-tartrate of soda, and sugar, are binaxial.

FIG. 26.



161. If a ray of light passes out of one medium into another of different density, it is bent aside out of its rectilineal course. This change of its course produces the refraction of light. Its amount depends directly on the nature of the two media traversed by the light. So that when a ray of light coming out of the air passes through glass, the result may be estimated by that index of refraction which is offered by glass in connection with the atmosphere. The different colours — red, orange, yellow, green, light blue, dark blue, and violet—form a second element of the change. Thus the red rays experience the least, and the violet the greatest refraction. If the former pass from air into water they have an index of refraction amounting to but 1·3309; while the latter have one of 1·3442. If we suppose that a colourless ray, *l i*, which contains a mixture of all possible coloured undulations, has to pass through the body, *a b*, Fig. 27, whose limitary surfaces are not parallel, the red rays will appear as *i r*, and the violet as *i u*. And if the several tracts of colorific undulations, *r e* and *u e*, emerge in such a way as to allow their differences of colour to be verified by the eye, it is evident

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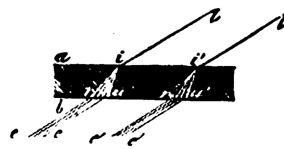
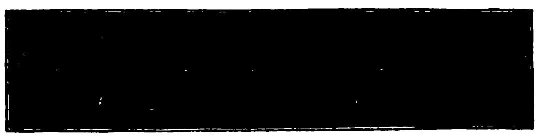
that we shall get a coloured image instead of a colourless one. On this fact depends the chromasia or coloration of a lens, and of the human eye. And it hence becomes an object to make the microscope and telescope achromatic: *i.e.* to arrange them so that as little colour as possible may be produced by the refraction of light.

FIG. 27.



162. Let us suppose that *A B*, Fig. 28, is the path of a ray of light, and that the movement of the molecules of luminous æther begins at *b*; it will require a certain time to propagate the disturbance from hence to *B*. Hence by the time that its neighbouring molecule begins to move, *b*

FIG. 28.



must have already travelled over a part of its path of semivibration, *bb′*. And since this movement proceeds from atom to atom, there is a molecule, *c*, which only begins to vibrate when *b* has completed a perfect cycle of vibration, from *b* to *b′*, back again from *b′* to *b*, and thence from *b* to *b″*, and back from *b″* to *b*. The distance from *b* to *c* is called the length of a wave. It is the interval between two molecules, which vibrate similarly at all periods of time, and one of which precedes the other by a single complete and perfect vibration. Under these circumstances *bf* corresponds to half an undulation.

163. The colours differ in the length of their waves. Each undulation of the most external red of the prismatic spectrum has a length of $25\frac{1}{2}$ millionths of an inch; while that of the other rays, or the interval *b c*, Fig. 28, is for orange 23, yellow $21\frac{3}{4}$, green 20, light blue $18\frac{3}{4}$, dark blue $17\frac{3}{4}$, and extreme violet 16, millionths.

164. If the velocity of propagation be unchanged, the number of vibrations occurring in an unit of time must obviously be inversely as the length of the undulations, so that the extreme red will have the smallest, and the extreme violet the greatest number. The former has 439, and the latter 697, billions of vibrations in the second. But this is only true of the atmosphere. If a ray of light passes into a more refractive medium, the velocity of its propagation is diminished.

165. The rest or movement of a molecule of the æther, *b*, Fig. 28, will depend on the amount and direction of the forces by which it is acted upon. Supposing that two excitements of equal amount impel it in the same path, the intensity of its vibration will be doubled. But as it is this

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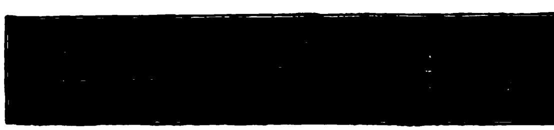
which determines the luminous intensity of each elementary ray, this latter is also increased. On the other hand, if we imagine that one force seeks to impel *b*, Fig. 28, towards *b b″*, and a second of equal amount at the same time urges *b* towards *b b′*, the two disturbances must mutually destroy each other. And the molecule *b* remains at rest, *i.e.* in spite of the double impulse, darkness is produced. This phenomena is called the complete interference of light.

166. Let us imagine *A B* and *C D*, Fig. 29, to be two rays of light which meet each other at an inconceivably small angle, and whose corresponding undulations take a similar course,—the molecules *b c d d′* will vibrate with a velocity twice as great as if only one of the two rays

FIG. 29.

were present. But this can only happen when the path of the rays differs by twice, thrice, or generally by some multiple of the length of an undulation *a d′*. Here the light is increased. While, on the other hand, where the paths differ by half the length of an undulation, we get a complete interference, such as is exhibited at Fig. 30. The molecules of

FIG. 30.



the æther, which lies midway between *a* and *c*, would vibrate till *b*, if only the ray *A B* were present. But it is evident that the dotted track of undulation which corresponds to *C D*, simultaneously moves upward with precisely the same force. Therefore it remains at rest. But it is obvious, that any difference in the paths of the rays *A B* and *C D* which amounts to half an undulation, or an inexact multiple of the same, must produce this mutual annihilation of the forces. It is therefore this difference which determines whether light, added to light, produces light, or darkness.

167. When the vibrations of the luminous æther are compelled to propagate themselves through a narrow fissure, their undulations suffer certain changes, the results of which are named inflection of light. The phenomenon may be illustrated by comparing it with the meeting and subsequent diffusion of the waves in water streaming through a small sluice. Such an alteration in the waves of light leads to the most manifold phenomena of interference.

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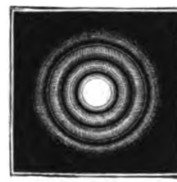
168. If rays of light of only one colour, which have passed through a very small round opening, are received upon a screen, or looked at with a magnifying-glass, we see in the middle a bright and coloured circular area, which is surrounded by a series of dark and light rings, as shown at Fig. 31. The complete interference of the luminous waves which diffuse themselves behind the narrow orifice produces the black circular bands, the breadth of which depends on the length of the undulations. Hence the appearance differs with different colours. For instance, if we interpose a red glass between the solar ray and the aperture through which it passes, we get the broadest stripes, because the luminous undulations which interfere are in such a case the longest. On the other hand, violet exhibits the smallest bands. So that we have here a means of measuring the length of the waves in the different colours.

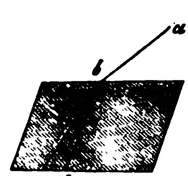
FIG. 31.



169. If we repeat this experiment with colourless sunlight, we find that the bright median area is enclosed by a series of circular bands possessing all the colours of the rainbow. Colourless light consists of luminous waves of all possible colours in a state of mixture, which renders it impossible for the eye to detect the particular ingredients. But since the breadths of the dark and light bands vary with the difference in length of the waves of the several colours, many of these are almost or quite extinguished in particular places, while others gain in luminous intensity. Hence what is called colourless light produces interferential or entoptic colours. These are found when light has to pass through very small apertures, or through thin layers of fluid, or unequal strata of solid, bodies. The iridescence of tendons, of the tapetum in the eye of some mammalia, and of the peritoneum of some fishes, together with the reddish colour exhibited by the fibrous-like elements of the areolar tissue of some animals when under high magnifying powers, are instances of such physical and accidental developments of colours which do not originally exist.

170. When a ray of light, *a b* (Fig. 32), has to pass through a simply refractive body, it experiences a deviation which is exactly proportionate to the refrangibility of this substance. For instance, it passes towards *b c* or *b d*, according as this exerts a more or less powerful influence. In all cases it remains single, as at first. But if it passes through calcareous spar, or any other doubly refracting body, it exhibits for the most part two paths, or two rays, *b c* and *b d*; so that on looking through it we are able to see two images of one and the same object. The one, called the ordinary ray, follows the laws of

FIG. 32.



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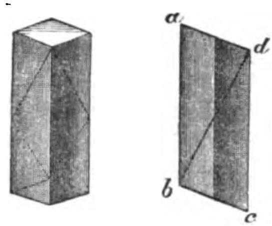
ordinary refraction, and has a definite index of refraction. But the second, or extraordinary ray, presents an index of refraction which, within certain limits, increases or decreases in proportion to the direction of the original ray at its entrance. Both rays contain polarized light, and their planes of polarization are at right angles to each other. If we suppose *b c d e*, (Fig. 25, p. 53) to be the transverse plane which is perpendicular to the ray of light, and *f g* to be the plane of polarization of the ordinary ray, then if *f a k* be a right angle, *k l* will be that of the extraordinary ray.

171. A Nicol's prism consists of two prisms of calcareous spar, *a b d*, and *d b c*, (Fig. 33,) which are cut in definite directions, and are united by means of Canada balsam at *b d*. If a ray of light passes upwards through it from *b c*, the ordinary image is reflected by the Canada balsam, *b d*, while, on the other hand, the extraordinary ray passes out at *a d*; and since the main sections *a b d* and *a b c* are parallel, it is single and not double. So that such a prism has the advantage of offering only one polarized luminous image.

FIG. 33.



172. Many optical properties of the animal tissues are examined by means of a microscope provided with a polarizing apparatus such as is delineated at Fig. 34. A Nicol's prism, *b*, is fixed under the stage, between the illuminating mirror, *f*, and the object disc, *e*. The latter is divided into parts of a circle, and is capable of being rotated horizontally. The uppermost part of the microscope tube, *a*, bears a circular plate, *d*, divided into 360 degrees, on which the index of the frame around a second such prism, *c*, plays horizontally. This latter is fixed upon the eye-piece of the microscope, and is called the analyzing prism, while that below is the polarizing one.

If we imagine that *c* is absent, and that all side-light is cut off by a screen, the object present at *e* can only be perceived in polarized light by means of the lower prism *b*. And, on adding the upper Nicol's prism, we obtain results which are modified by its position.

Supposing that *f g* (Fig. 25, p. 53) is the plane of polarization of those rays of light which emerge from the under prism, they will pass unimpeded when the upper one presents a plane of polarization having a similar position. This, for instance, is the case when the graduated disc, *d* (Fig. 34), rests at 0° and 180°; we then get the greatest possible strength of illumination. On the other hand, if we turn the upper prism, *c* (Fig. 34), so that the index points to 90° or 270°, its plane of polarization corresponds to *k l* (Fig. 25, p. 53); while the pencils of light ascending from the lower Nicol are polarized in the plane *f g*. So that those rays of light, the

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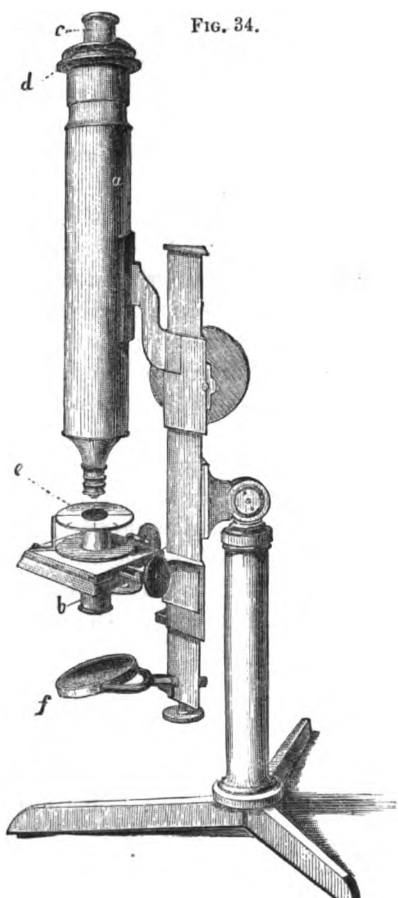
molecules of which vibrate at right angles to the plane of polarization, cannot pass through the upper prism, and we get the greatest possible obscurity. And since all intermediate directions allow one part of the light to pass, and repulse another, we might argue, *à priori*, what phenomena must result from our changing the position of the upper prism. If we turn it round a whole circle, we shall have two places of greatest illumination, viz. 0° and 180°, and two of greatest obscurity, 90° and 270°; the illumination will decrease from 0° to 90°, and from 180° to 270°; and will increase from 90° to 180°, or from 270° to 0°.

FIG. 34.



173. This fact sufficiently explains the way in which we may determine the saccharine or albuminous constituents of an animal fluid—for instance, of the urine—by means of the polarizing apparatus. Many fluids and gases — and amongst solids, the rock-crystal — possess the property of causing the plane of polarization of those rays of light which

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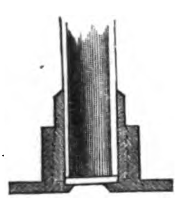
pass through them to deviate in the horizontal direction to a definite angle. Suppose that this plane occupied *f g*, Fig. 25, p. 53, it would be in *h i* when moved towards the right, and in *m n* when towards the left. In this way what is called circular polarization is produced: and the body which causes it, is said to possess a certain rotative capacity.

Pure powdered starch—as for instance, inulin—turns polarized light towards the left (←——), while the dextrine into which it is transformed, as it undergoes fermentation to become grape-sugar, turns it towards the right (——→). And if grape-sugar has not been solid, but has been from the beginning in a state of solution, it turns the plane of polarization towards the left side. Pure cane-sugar, sugar-candy, and sugar of milk, exhibit a deviation towards the left. Other circumstances being equal, the magnitude of the angle of rotation depends on the density of the solution. For instance, in a solution containing only 1 per cent. of sugar-candy, the rotation forms an arc of 0° 53′: but with 11 per cent. it amounts to 10° 10′.

Let us imagine we had interposed a tube (Fig. 35) closed below by a transparent glass plate, between the polarizing and analysing prism; the relations of brightness and darkness, just mentioned, would be no way altered by the fact of this tube containing water or any other indifferent fluid. If the upper prism corresponds to *f g*, Fig. 25, p. 53, we have brightness, if to *k l*, darkness. But if we replace the water with a solution of sugar-candy, the plane of polarization is turned towards the right through a certain angle, *f a h*. And hence the place of greatest illumination no longer corresponds to *f g*, but to *h i*.

FIG. 35.



174. Turning to the polarizing microscope delineated at Fig. 34, p. 59, it is easy to see how this acquaints us with the optical properties of any small objects which lie upon the stage *e*. Of these properties we may make three chief divisions.

1. The microscopic object has the capacity of changing polarized light in general. It depolarizes it, so to speak. By its influence, the polarizing effect of the lower prism is suspended: so that the upper one loses its properties of complete interference. The microscopic body allows rays of light to pass through the whole length of the instrument, even when we have obscured all the rest of the field of vision by placing the planes of polarization of the two prisms at right angles to each other. We may represent this condition by the completely luminous margin, *a*, Fig. 36.

2. The body of which we take a magnified view, does not possess a power of double refraction. The ascending polarized ray is turned aside from its rectilineal path. But it remains single and polarized. Assuming its plane of polarization to be in 0° and 180°, it appears luminous, although the similar plane of the analysing prism remains at

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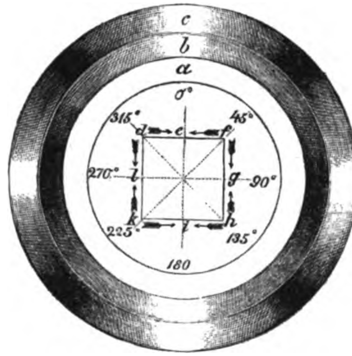
0° and 180°: and, *vice versâ*, it is dark when this is at 90° and 270°. Representing the object in the form of a circular band, we necessarily find two places of greatest brightness, and two of greatest darkness; an appearance such as *b*, Fig. 36, seeks to exhibit. These points would deviate by an angle of definite amount, if the interposed object were capable of rotating the plane of polarization (§ 173).

Fig. 36.



3. The microscopic object possesses doubly refracting powers. The polarized ray which ascends from the lower prism divides itself into two such rays, which have planes of polarization at right angles to each other. We will next see how this result is affected by collateral circumstances.

Let us assume that the planes of polarization of both prisms lie in 0° and 180°, so that the field remains at its greatest illumination. If the two planes of polarization of the doubly refractive object are at *e i* and *g l* (Fig. 36), the former can pass in full strength through the upper analysing prism; while the latter is utterly insusceptible of its influence. We get the same result when we rotate the object disc through 90°; so that *e i* corresponds with 90° and 270°, and *g l* with 0° and 180°. If the doubly refracting body forms a circular band, *c*, we have four places completely illuminated, namely, 0°, 90°, 180°, 270°. And by turning the upper prism round 90°, and allowing the object itself to remain undisturbed, the effect will evidently be repeated.

But supposing the plane of polarization for the under prism is at 0°, and 180°, while that of the upper is at 90°, and 270°, the field of vision will be dark. And if we now insert the doubly refracting body in such a way that one of its planes of polarization runs from 45° to 225°, or in *f k*, while the other similarly passes from 135° to 315°, or in *d h*, it will introduce new relations.

A luminous molecule, *g*, of the upper prism, is similarly impelled by each of the rays of the doubly refracting body:—viz., by that whose plane of polarization passes in *f k*, in the direction and with the force, *f g;* and by that whose plane is in *d h*, in the same way, and with the same amount of force, *h g*. Hence *g* vibrates with double force: and we get brightness at 90°. And since this is repeated for *i*, *l*, *e*, and *g*, we have four luminous places in the whole circle.

The molecule, *f*, of the upper prism—which is inclined to its polarizing plane at an angle of 45°, and corresponds to one of the planes of polarization

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of the doubly refracting body—necessarily behaves exactly the reverse of this. Since *g l* is the only permeable plane of the upper prism, *f* can only vibrate with the direction and amount of impulse, *f g*. That ray of the doubly refracting body which corresponds to *d h*, would certainly be able to satisfy this requirement. But the second ray, *f k*, furnishes an exactly equal force, *f e*, in the opposite direction. Hence the molecule, *f*, of the upper prism must remain at rest. The direction of the arrows may serve to render this description more intelligible. We shall therefore have darkness at 45°, 135°, 225°, and 315°.

In short, a doubly refracting body, which possesses the form of a circular band, exhibits four dark places, and four of the greatest possible brightness, such as are roughly shown at *c*. And by turning round the upper prism, or the object itself, at every 45° what was dark will become light, and *vice versâ*. In singly refractile bodies the same change only obtains after a rotation of 90°. In rotating through an entire circle, *b*, any given point of the latter exhibits itself only twice light, and twice dark; while that of a doubly refractile mass is four times lit up, and four times darkened, *c*. Finally, a depolarizing compound remains bright in all positions, *a*.

175. Under these circumstances, it sometimes happens that there are differences in the paths of the luminous rays: this is especially the case in doubly refractile bodies. We not only get the dark spots which arise from a complete interference, but also the polarizing colours which are produced by the interference of polarized light. For instance, if we introduce a lamina of gypsum of proper thickness into the stage of the polarizing microscope (Fig. 34, p. 59), and rotate the upper prism through an entire circle, the field of vision appears in the first quadrant of the rotation as a beautiful green, in the second red, in the third again green, and in the fourth again red. The intensity of the colour diminishes considerably as we approach the boundary of each quadrant.

176. In the structures of the animal body we find examples of almost all the cases which we have hitherto contemplated generally.

The microscopic crystals of carbonate of lime (Tab. I. Fig. IV.), which form the otolithes of man, mammals, birds, and some reptiles, as well as the cretaceous masses of the membranes of the nervous centres, and of the lime sac of the frog,—all exhibit the most splendid colours of polarization. In Tab. I. Fig. V., some of these are seen in the luminous field at 0°, *i.e.*, where the planes of polarization coincide for both prisms. In Fig. VI. they are represented in the clear-obscure field of a 60° inclination of the upper prism: in Fig. VII. they are shown in the dark field of 90°. But no drawing can do justice to the metallic or star-like light, and the beautiful intensity of colours which are seen in this last position. Tab. I. Fig. VIII. exhibits similar appearances of the crystalline globules which occur in the urine of the horse (Tab. II. Fig. XX.). It is unnecessary to

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state that these colours vary according to the way in which the structures lie on the glass plate of the object stage, or with the surfaces which the light penetrates, and the directions which it takes. This will be perceived on an attentive examination of the figures referred to.

In ordinary researches we are sometimes unable to decide whether very small bodies are really crystals or not, since their form remains undefined even under high magnifying powers. The lustre which they exhibit in the dark field of the polarizing microscope is now and then useful, as affording grounds for a more definite decision.

177. It was found by C. von Erlach, that most animal and vegetable tissues belong to the class of doubly refracting substances. So that a muscular or nervous fibre which has been arranged in a circular form, exhibits four places of deepest shade, and four of greatest light, as shown in the diagram at *c* (Fig. 36). But if the object disc *e* (Fig. 34) be rotated, the point formerly dark will become light, and *vice versâ*. The movement of the analyzing prism leads to similar changes of appearance. The effect is augmented when the parts have lain some time in water, so as to acquire a dull appearance.

178. Tissues composed of concentrically arranged strata offer phenomena of two kinds. According to Erlach the doubly refractive power of those extremely thin layers which form the crystalline lens is not in the least shown by polarized light. On the contrary, the most prominent optical phenomena which they exhibit are those belonging to a series of flat and singly refractive bodies. An ordinary ray of light, which falls upon a number of glass plates lying one upon another, makes its exit in a polarized state. And if the same holds good for the crystalline lens, the condition will be that represented in the diagram at *b*, which, in fact, Erlach observed it to be. The crystalline lens of man and frogs exhibits the cross represented in Tab. I. Fig. XII. with great distinctness in the darkened field of vision.

179. The granules of starch also consist of a number of more or less eccentric layers, arranged around a middle point, which is called the umbilicus. Their doubly refractive power is most energetic. Tab. I. Fig. IX. exhibits a large granule of potato starch in the luminous field, and shows the light and dark streaks directed towards the middle point of its unequally concentric strata. In Fig. X. we see the same granule, in the dark field which is produced by rotating the upper prism through 90°. The sharp black lines occupy the places of previous lights, and the bright masses those of the shadows. Finally, Fig. IX. exhibits the same granule, in the same dark field, after it has been so far rotated by means of the object disc, that the shadows correspond to the dark parts of Fig. IX., and the bright ones of Fig. X. The dark lines now deviate 45° from those seen in the second case.

If the umbilicus lies exactly in the middle of the visible part of a

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spherical starch-granule, the dark lines form a black rectangular cross. If it be eccentric, the four black arms are distorted. This want of uniformity may result in the production of one or more additional stripes of shadow, a condition represented in Figs. 37 and 38.

FIG. 37.

FIG. 38.

180. An examination by polarized light sometimes leads to beautiful phenomena of colour, and furnishes us with some of the most attractive objects which can be seen under the microscope. And another reason renders it of important service to physiology. These affections of the luminous vibrations reveal molecular conditions which cannot be verified in any other way, or, at any rate, not with equal delicacy. It is very possible that muscles and nerves, in the states of activity and of rest, or under normal or abnormal conditions, exhibit differences which can only thus be ascertained.

181. While cohesion and pressure keep up the mutual attraction existing between the atoms of bodies, HEAT seeks to remove them to a distance from each other. All ponderable matter expands under the influence of a higher degree of temperature. The cohesive state causes important differences in this respect. Elastic fluids obey the impulse of heat much more than liquids or solids.

182. By a rise of temperature from 32° to 212°, a glass tube elongates from $\frac{1}{1095}$th to $\frac{1}{1238}$th of its previous length, an oaken stick $\frac{1}{833}$rd, and a similar piece of tin to about $\frac{1}{400}$th. Water exhibits the peculiarity that its greatest density is not at 32°, but at nearly 39·2°; so that a cubic inch weighs less at the former temperature than at the latter. And taking its condition at 39·2° as unity, the space occupied by pure water at 210° to 212° amounts to 1·043; while from 99° to 100°, it is 1·0066 to 1·0069. If it contains other bodies, these relations to temperature are changed. For instance, if 1·23 per cent. of salt be dissolved in water, its maximum density is at 34·16°.

183. It is evident that variations of temperature can only change the absolute dimensions of the solid and liquid parts of our body in a very inconsiderable degree; a degree which under ordinary circumstances may be altogether disregarded. But on the other hand we have seen (§ 110) that a rise of temperature greatly facilitates the passage of fluids through fine tubes, and considerably alters those phenomena in which cohesion is concerned. Hence changes of temperature have a very important influence.

184. It is probable that every solid or liquid is capable of being con-

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verted into an elastic fluid or vapour, under the influence of a certain degree of heat. In the change itself a certain quantity of heat is lost: in the act of vaporization it is, as it were, chained down, or, in ordinary language, rendered latent. When the vapour returns into the liquid form this latent heat reappears free. Thus vaporization becomes a means of cooling bodies, and the condensation of vapours to liquids is capable of imparting warmth. The watery vapour which comes from the blood and the nutritional fluid, and which is continually given off through the lungs and skin, thus forms one of the means by which temperature is lowered. And when we inhale cold air, a part of the vapour contained in the warmer respiratory air which was previously present in the lungs is condensed into liquid water: and a certain quantity of heat is thus set free.

185. The latent heats of vapours are reduced to what may be called units of temperature, *i.e.* to those weights of the liquid to be vaporized, which the same quantity of heat would raise one degree. For instance, when we say that the latent heat of watery vapour is 972, we mean that the quantity of heat absorbed in the evaporation of one ounce of water, would be able to raise 972 ounces one degree. Alcohol would thus have a latent heat of 633, and æther 295.

The amount of latent heat varies with that of the temperature. Some experimenters assert that the sum of the given active temperatures, and the units of heat determined for these, is a constant magnitude, which obtains at all temperatures. The estimate 972 is that of water at 212°. This therefore amounts to the constant magnitude of $972+212=1184$. But if the water in our lungs evaporates at a temperature of 99·5°, the latent heat of the watery vapour will be $1184-99{\cdot}5=1084{\cdot}5$. But more careful experiments do not appear to confirm this presumption.

On an average 239·382 grains of water evaporate from my lungs every hour. Omitting all nicer considerations, and taking 1084·5 as the latent heat at 99·5 , we get a cooling power of ·36° for the whole mass of my body.

186. When a liquid evaporates in a confined space, this can only take up a certain quantity of vapour. And when it contains this maximum, it is said to be saturated. With less than this, it is said to be incompletely saturated. And supersaturation leads to the result that the surplus over and above the saturating quantity is deposited in the liquid form.

If we assume with Regnault that the tension of watery vapour at 32° amounts to ·1811, then a mass of 61 cubic inches of air, which is subject to a pressure of an entire atmosphere, or to 29·9 inches of mercury, and is cooled down to this temperature, will at most only take up ·0757 grains. If it contains less than this, it is incompletely saturated. If we force ·1 grain of watery vapour into it, ·0243 will fall down as liquid water.

187. Let us suppose we had three barometer tubes completely filled

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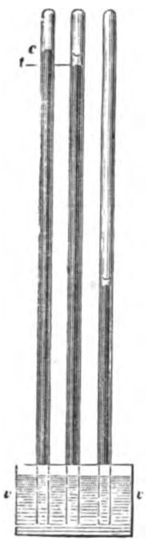
with quicksilver, and isolated by being placed upright in the same metal at *v v*, Fig. 39. The mercury sinks to *c*, or as far as the pressure of the atmosphere permits. If we now allow a drop of water to ascend in the middle tube, the mercury falls lower, for instance, down to *t*. And if we introduce a drop of æther in the same way into the right hand tube, then the quicksilver falls still lower.

FIG. 39.



The cause of this phenomenon lies in the collateral effects of evaporation. The drop of water present at *t* saturates the space above the mercury with aqueous vapour. But this possesses a certain force, by which its molecules tend to repel each other or extend themselves—a definite degree of tension or elasticity. It consequently presses on the quicksilver, and provides the inner surface of the metal with a counter-pressure for that tension of the outer atmosphere by which it has been driven up to the original level, *c*. So that this level undergoes a corresponding depression; and since, other circumstances being equal, the vapour of æther has a much greater tension than that of water, the mercury in the corresponding tube sinks much more than in the middle one.

Supposing that *c* stands 29·92 inches higher than the mercurial surface at *v v*, and that the barometer and thermometer remain unaltered, *t* will amount to 29·74 inches only, at 32°. The tension of the watery vapour is therefore equal to ·18 inches of mercury. And if that of the vapour of æther be 6·22 inches, the mercury in the third tube will descend to 23·7 inches.

But these estimates only hold good for complete saturation. Just as a more diffused gas can only exert a smaller pressure, so the vapour which incompletely saturates a space exerts a smaller tension.

188. But if, on the other hand, a space which is void of all diffusible fluid is saturated with vapour, and is then increased by a diminution of the pressure upon it, the state of saturation ceases. The vapour immediately diffuses itself, and its tension sinks; while, *vice versâ*, if the pressure at which saturation had occurred be increased, a part of the vapour corresponding to the diminished space will fall down in the liquid form.

We have seen that 61 cubic inches of air at 32° and 29·9 inches barometer are saturated with ·757 grains of aqueous vapour. The tension of this vapour equals ·1811 inches of mercury. If the temperature remains unchanged and the pressure diminishes to 14·96, this mass of air will dilate to 122 cubic inches. And thus it will be only half saturated for 32°; and the vapour itself will have a diminished tension.

If the pressure were increased to two atmospheres, or 59·8 inches of

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mercury, the 61 cubic inches would be reduced to 30·5. And this quantity of air would only take up ·378 grains of water-vapour at 32°. Hence ·378 grains of water have been deposited. So that it may be generally stated that pressure only affects evaporation so far as it increases or diminishes the space at the disposal of this process.

189. From the preceding statements it results that the tension of vapours, and the external pressure of the atmosphere, behave like two opposing forces. For instance, if I saturate with aqueous vapour a space of air at 32° and 29·92 barometer, it is just the same thing, for it as though the pressure of the atmosphere amounted to only 29·74 inches of mercury. But since gases expand proportionately to their tension, saturation with vapour affords a means by which their space may be increased. This fact holds good for the air we breathe.

Let us assume that we breathe in a perfectly dry atmosphere at 29·92 inches barometer, and 32°; and that our breath, after being saturated with aqueous vapour in the lungs, is expelled with a vaporous tension of 1·39 inches of mercury: it will follow that the expired air sustains an external pressure of only 28·53 inches. Disregarding the differences in the diffusion of heat, the respiratory air which occupied 61 cubic inches in the dry state, will, under such circumstances, take up 64·07 cubic inches.

190. A fluid boils, when the tension of its vapour at the boiling heat equals the pressure of the atmosphere. Hence, at the level of the sea, watery vapour of 212° has a tension equivalent to 29·9 inches of mercury. But if we ascend a high mountain, on which the barometer stands much lower, water can be made to boil below 212°.

This influence of the barometer holds good for lower degrees of temperature, since the space which the vapour takes up becomes proportionately enlarged, or the counter-force which limits its tension is diminished. Hence, other circumstances being equal, the lungs and the skin give off more watery vapour at a low condition of the barometer than at a high one.

191. While pressure only acts indirectly (§ 188), warmth exerts a direct influence on the formation of vapour. The tension of vapour increases with the temperature in a disproportionate degree. But since the density also increases with the tension, it is evident that the more a given space is heated the more vapour can it take up.

Although watery vapour has a tension of only ·1811 inches at 32° and 29·9 inches barometer, it amounts to 1·242 at 86°, 1·392 at 89·6°, 1·838 at 98·6°. Hence the vapour which rises at the temperature last mentioned is 10·15 times as dense as that at 32°.

The elasticity of vapours rises rapidly at higher degrees of temperature. At 212° that of water has the tension of one atmosphere, or 29·9 inches of mercury; at 250·5° it amounts to two, at 358·88° to ten, and at 510·6° to fifty, atmospheres. This tremendous force of heated vapour,

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which easily shatters the strongest vessel, may also obtain in the human body. For instance, in a person who perished from burning on a railway, the walls of the belly were found torn asunder, the tension of the watery vapour produced in the wall of the abdomen having soon overcome the resistance of the abdominal walls.

192. Although 61 cubic inches of air at 30 inches barometer and 32° only take up ·0747 grains of watery vapour, yet the same quantity of air, heated to 98·6, takes up ·6332 grains. From this we see that the weight of vapour increases with the elevation of temperature, but in a smaller proportion than the tension. This amounts to ·1811 inches at 32°, and 1·8383 at 98·6; so that, according to this ratio, 61 cubic inches of air should contain ·7682 grains of watery vapour.

The cause of this difference lies in the change of dimensions. When we heat 61 cubic inches of air from 32° to 98·6°, they expand to 69·33 inches. And, if saturated with watery vapour at 30 inches barometer, they remain under a pressure of $29{\cdot}92 - 1{\cdot}84 = 28{\cdot}08$ inches. Hence the 69·33 inches are again expanded and become 73·84 inches. And this latter bulk can certainly take up ·7682 grains of aqueous vapour, while 61 inches of it will of course only take up a smaller amount. Thus when we compare the same volume of air saturated with vapour at different temperatures we get units which are not equivalent to each other. A cubic inch of warmer air is, in itself, less than a cubic inch of colder air. And only the application of stronger pressure in a closed vessel will enable us to correct this inaccuracy.

193. What has been here laid down generally is repeated, step by step, in the phenomena of respiration. The air is heated in the lungs, and if it remains there long enough, becomes saturated with watery vapour. The gases exhaled are therefore only subject to a small amount of external pressure; and both on this account, and by reason of their higher temperature, they are more rarified than the air of inspiration. The quantity of water which is necessarily given off from the blood varies, both with these phenomena, and also with the temperature and vaporous state of the inspired air.

194. That interchange of gases which occurs in the lungs, and which will be subsequently considered, may at present be set aside. We will suppose that we breathe a completely dry atmosphere at 59° and 29·9 inches barometer, and that, in the lungs, this air is raised to 98·6°, and saturated with watery vapour. Under these circumstances, 61 cubic inches of air take up ·6332 grains of watery vapour; which our bodies must give off. But if the inspired air contained ·20078 grains in a state of saturation, or ·07722 in an incompletely saturated state, less would be required of the blood, which would find an exit for its superfluous water in the urinary organs. It also follows, that other circumstances being equal, the drier the atmosphere, and the greater the difference of temperature

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between the air inspired and expired, the larger the amount of water which is evaporated from our bodies. And this explains how such variable quantities of water may be evacuated by means of the urine, or the pulmonary and cutaneous exhalations.

195. Under the influence of higher temperatures, the space occupied by gases is considerably increased. But the degree of expansion varies with different gases. The index of expansion is that fraction of a given unit of volume, by which the total dimension of a gas increases, when it is heated to a given amount.

Thus a cubic inch of air at 32°, becomes 1·3665 cubic inches at 212°. Hence the index of expansion for this limit of temperature amounts to ·3665. If we assume that this difference is equal for all equal subdivisions within this limit, a cubic inch of atmospheric air would occupy 1·003665 at 33·8°, and 1·136 at 98·6, while at 27° it would amount to ·98982 cubic inches. The index of expansion for carbonic acid is ·37099.* One cubic inch of this gas at 32°, therefore amounts to 1·137 at 98·6, and consequently occupies a greater space than atmospheric air.

196. In respiration this difference also obtains. Other circumstances being equal, the respired air undergoes a greater expansion, the more its temperature is increased in the lungs. And the interchange of gases which respiration produces leads to a peculiarity worthy of notice. In the absence of sufficiently delicate observations, it may be assumed that the expansibility of oxygen and of nitrogen does not essentially differ from that of the atmosphere as a whole. While, on the other hand, we have seen that the index of carbonic acid is somewhat greater. In respiration, a certain volume of carbonic acid replaces a part of the oxygen. Even supposing that one volume of carbonic acid is expelled for one volume of oxygen absorbed—which is, however, by no means the case—even then the bulk of the expired air would be considerably increased by the greater expansibility of carbonic acid.

197. Under the influence of external heat, every substance rises in temperature. But it is the nature and molecular condition of the substance that determine how much heat is necessary to raise its temperature one degree. The amount thus necessary forms the specific heat, or calorific capacity, which belongs to each particular kind of matter.

If we mix a pound of water at 32° with a pound at 59°, the whole has a temperature of 45·5°; since both the substances and their amounts are the same. But if the experiment be repeated with a pound of water at 32°, and a pound of quicksilver at 59°, the mixture will have a temperature of 32·87°. So that the quicksilver has lost 26·13°, in order that

* The reader ought to be reminded that, although later observations appear somewhat to modify the result deduced by Dalton and Gay Lussac, viz., that all gases have an expansion amounting to ·375 from 32° to 212°, still the differences thus observed are so suspiciously small, that, all things considered, we can scarcely lay much stress on the ingenious argument based upon them by our author in the following paragraph.—(EDITOR).

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the water might gain ·87°. Hence the latter takes up 30·011 times as much as the former; or, in other words, the capacity of the water for heat is 30·011 times greater than that of the quicksilver. And hence taking that of water as unity, the specific heat of mercury amounts to $1 \div 30{\cdot}011 = {\cdot}033$.

198. Many substances, such as water, exhibit equal specific heats for all degrees of temperature. This forms an additional reason why the specific heat of pure water should be made use of as an unit with which that of other bodies may be compared. Many other bodies change their specific heat, according to their state of temperature and cohesion. For instance, from 32° to 212°, glass has a specific heat of ·177; while from 32° to 572°, it amounts to ·19. Charcoal is ·24, mineral coal ·20, and the diamond ·15. Here the specific heat decreases as density increases. Hitherto we are unaware to what extent these influences affect the animal tissues.

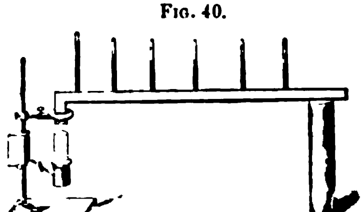
199. A pound of quicksilver must give off 30°, in order to raise a pound of water one degree, and its specific heat is therefore only ·033 (§ 197). It is thus evident that the greater the specific heat of a body, the less its temperature is raised by equal amounts of heat. Those animal tissues which have a smaller specific heat than water, are so far placed at an advantage.

200. Most of the estimates made for the different textures are of such old date, as to require to be verified by newer and more delicate methods of investigation. Thus the bright red arterial blood had a specific heat of 1·03, and the dark red venous ·89. The same amount of heat which raises 15·44 grains of water one degree, will therefore only raise as much arterial blood to $1 \div 1{\cdot}03 = {\cdot}97°$; and venous blood to $1 \div 89 = 1{\cdot}12°$. Muscle exhibits a specific heat of ·74; and fatty bodies, such as wax or spermaceti, ·40 to ·45. The same heat would therefore raise the temperature of these two kinds of tissues respectively half as much again, and twice as much, as arterial blood.

201. The gases concerned in respiration have very small specific heats. The atmosphere is ·267, nitrogen ·275, oxygen ·236, and carbonic acid ·221. So that comparatively little heat is lost in imparting warmth to the inspired air in our lungs.

202. When a body is heated at any particular point, the heat is propagated from one particle to another of its mass. If we provide a rod with a series of holes containing quicksilver, and place thermometers in these, as shown at Fig. 40, we shall be able to verify the differences of temperature for the different distances. A substance which

FIG. 40.



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propagates heat quickly and completely throughout its whole extent, constitutes a good conductor: while one which exhibits characters directly the reverse of these, is called a bad one. In the former case, the thermometer on the extreme right rises considerably: in the latter, it remains at a lower level.

The metals belong to the class of good conductors; while the various woods are bad ones. Hence, when a metallic plate is heated to a glow at one end, and we lay hold of it at the other, we burn ourselves. While, on the other hand, we are able to hold a burning splinter of wood, or a wick of flaming cotton, or a charred bone, without the least damage.

203. Let us suppose that any source of heat is inclosed in a covering of some foreign mass: it is evident that the conducting power of this latter will exercise an important influence on the state of its temperature. If the enclosing substance belong to the class of good conductors, it takes up a considerable quantity of heat, and gives it off to the surrounding air, according to the difference of temperature and the specific heat of the same. But if it be a bad conductor, it will retain the warmth derived from the supposed source of heat; and thus forms an insulator, which prevents any unnecessary loss.

204. We shall hereafter see (§ 209) that a certain quantity of heat is continually being produced in the interior of our bodies. The changes occurring in the blood and solid or semisolid tissues form a continual source of heat. The skin, the hair, and the nails, constitute external coverings which surround and enclose the whole. And since all these horny masses belong to the class of bad conductors, they prevent the losses of temperature which would otherwise obtain.

205. The use of clothes is based upon the same principle. All those kinds of vegetable fibre and animal tissues, which we make use of as clothing, possess low degrees of conducting power. They only strengthen and assist the protective coverings previously given us. Hence man, who is naked, finds clothing necessary; while the hairy mammal or the feathered bird is freed from this requirement. Hence also wooden houses are comparatively warmer, and iron colder, than stone ones.

206. If an organized body, which is incapable of volatilizing as a whole, be exposed to a continually increasing heat, it first loses those constituents which are vaporized at comparatively low temperatures. If water is present, either in the form of a mixture or in that of a hydrate, it is first driven off; either alone, or in combination with ammonia and other volatile compounds. If the temperature rises beyond this point, and sufficient oxygen is present, it combines with the carbon of the organized body to form carbonic acid, and with its hydrogen to form water. If, on the other hand, the necessary quantity of oxygen is not furnished, this change occurs only partially. Frequently, other combinations are produced; which we distinguish by the name of empyreumatic

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products; and the whole mass becomes blackened. It is usual to say that it is carbonized or charred; and to assume that it is only the surplus and remaining carbon which causes the change of colour. But the increase of colour has no uniform proportion to the quantity of carbon which has been unable to combine with oxygen to form carbonic acid.

207. All these phenomena may occur in our bodies. When a part of the skin is slightly burnt, it becomes harder and drier, from having had to part with a portion of its water. While the application of a red-hot iron to a certain extent of the surface of the body chars all the structures sufficiently exposed to it. No part of the body can completely withstand great heat: and human beings, who have perished by fire, are often so perfectly consumed as to leave scarce any relics.

208. When a higher temperature converts water or other volatile compounds into vapours, the heat thus rendered latent makes the evaporation a cooling process (§ 184). But when a body burns, a certain amount of heat is produced, and constitutes its heat of combustion. It also may be reduced to units of temperature, just as the latent heat was (§ 185).

If ice is converted into water of 32°, 140 units of heat are combined with it in the process of thawing. Hence a pound of water at 172° will convert a pound of ice into water of 32°. Now when we say that the combustive heat of carbon amounts to 96·5, we mean that a pound of burning charcoal is able to melt 96·5 pounds of ice at 32°. Hence the units of temperature actually set free are equal to $140 \times 96{\cdot}5 = 13510$. The amount of heat produced in the combustion of one pound of charcoal would suffice to raise 13510 pounds of water one degree. And the combustive heat of hydrogen being 295·59, this will similarly give 41382·6 units of temperature, or more than thrice the amount of charcoal. It must, however, be remarked, that these basic numbers — and especially that of hydrogen — are by no means so trustworthy as their importance in many physical, chemical, and physiological questions might make us wish.

209. The lungs and skin are continually introducing into the body a certain quantity of air. But this causes a part of the carbon and hydrogen of its organic compounds to undergo combustion, with the formation of carbonic acid and water. If we suppose that—contrary to what really happens—the carbon and hydrogen unite as simple substances with oxygen, the heat thus set free might easily be deduced from the preceding estimates. This oxidation forms the chief internal source of that heat, the unnecessary loss of which is provided against by the horny coverings on the external surface of our bodies.

By way of example, we will adduce the following calculation. On an average I take 7·89 grains of oxygen into my lungs every minute. Supposing that this serves to burn up 1·83 grains of carbon, and ·3768 grains

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of hydrogen, the former would suffice to raise 13510 × 1·83, or 24723·3, and the latter 41382·6 × ·3768 or 11596·6, and both together 36320 —grains of water to one degree. The 3·985 grains of water which are converted into vapour in my lungs during every minute claim 3873·4 units of temperature (§ 185). The air which I respire and warm during the same period amounts to 139 grains. If its temperature is raised from 59° to 98·6°, 1469·67 units of temperature are thus lost (§ 201). Hence 30977 of the 36320 units remain.

The oxygen inspired changes the dark red venous into bright red arterial blood. The quantity of heat which would raise 30977 grains of water one degree, can produce the same result on 30074·6 grains of arterial blood. The venous blood entering the lungs was found by Breschet and Becquerel to be ·54° colder than the arterial blood returning from the same organs. Applying this estimate to the human subject, it would follow that 63320·4 grains, = 9 pounds and ¾ of an ounce, pass through the organs of respiration every minute. This example sufficiently shows how easily a whole series of circumstances may be calculated, provided one or two data are given with sufficient accuracy. But it does not give any trustworthy numbers, since the question has been simplified for the sake of distinctness; much having been altogether assumed, and much that is inaccurate having been nevertheless made use of as a basis. Since it is not pure carbon or hydrogen which undergoes combustion, but organic compounds of them, these are not the combustive heats really generated. And as yet there is such a want of physical research on this point, that it is absolutely impossible to estimate the heat developed in the absorption of the gases. Finally, it is very questionable whether the specific heat of the arterial blood really is so considerable. Taking venous blood as a basis, we shall get 72586·8 grains = 10 pounds 6 ounces, as the quantity of blood so passing; and if the higher temperature of the arterial blood turned out to be ·18° lower than our preceding estimate, it would raise the amount to 109652·4 grains = 15 pounds, 10·634 ounces.

210. A heated mass gives off rays of heat, just as a luminous one radiates light. Its density, and the nature of its surface, exert an important influence in this respect. A metallic surface radiates 8½ times as much when covered with lamp-black or white-lead, as when it is smooth and polished. According to Melloni, the radiative capacity of any particular metal increases with the decrease of its density.

211. The rays of heat which impinge upon a body may undergo very different destinies. They may be reflected in a single direction, depending on their angle of incidence; or they may be diffused and dispersed on all sides. While another portion of them may be absorbed by the mass against which they strike. Finally, they may pass through the substance which they meet, just as light penetrates a transparent body.

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Surfaces which offer no great obstacles to the radiation of heat, also absorb it with more ease: and *vice versâ*, when the former process is difficult, the latter is also impeded. Lamp-black has a great efficiency in this respect. Black clothing absorbs more heat than white; hence the latter is more agreeable in summer, since it reflects the external heat more freely from its surface.

212. Just as there are bodies which are opaque to rays of light, so there are athermanous bodies which allow no passage to those of heat. While a body which exhibits the reverse of this belongs to the class of diathermanous bodies, which have the same relation to heat as transparent substances have to light. And as we have seen that light contains rays of the most different colours, so something similar to this recurs with heat, the various kinds of rays exhibiting different indices of refraction (§ 161).

213. There are many substances which do not separate the various rays of heat. Thus, rock-salt allows all to pass through it, while lamp-black absorbs all just as indiscriminately. But on the other hand, there are many substances which absorb certain calorific rays, while they allow the passage of others. This property is called diathermancy, and the rays to which this farther course is conceded, are named thermanized rays. They behave to a certain extent like those coloured rays of light which have passed through a coloured body.

214. If we keep to this comparison with the luminous rays, we obtain results which are extremely important in a physiological point of view. We have seen (§ 161) that the seven prismatic colours possess unequal refracting powers. An analyzed solar ray presents a calorific, as well as a luminous, spectrum. But the former is of greater width than the latter—that is, there are calorific rays which possess a smaller refrangibility than the red, and a greater than the violet. And we may either suppose that the calorific spectrum really is wider, or that there is a part of the luminous spectrum which the eye is unable to appreciate. The latter view is more probably the correct one, since the researches of Bruecke indicate that certain of the more extreme rays escape us, in consequence of their being unable to pass through the cornea and crystalline lens of the eye.

215. If we conceive ELECTRICITY under the form of two fluids capable of exhibiting two kinds of properties, a positive and a negative, it is evident that the opposition of an equal positive and negative force will result in a state of indifference or neutrality. But if any cause calls forth an electrical tension, the two kinds of electricity divide themselves into different localities; the positive accumulates at one place, and the negative at another. And those extremities of a body which exhibit these peculiarities are called the positive and negative poles.

216. When once this separation has been brought about, there are

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two possible cases. One or both of the separated electricities remains in a state of rest, until the balance is once more equalized by secondary processes. The electricity of friction, as it is produced by the ordinary electrical machine, gives rise to this so-called static or tensional electricity. While the galvanic pile furnishes it in a state of movement, or as current electricity. And if it is confined to a circuit, the two opposite electricities are continually uniting with each other, while the plates of the pile are just as constantly developing new electric disturbances. The bodies which effect this are called electromotors, and those which form the paths that terminate and close the circuit are named the poles or electrodes.

217. The capacity of transmitting electricity in a greater or less degree distinguishes bodies into good and bad conductors. The metals in general belong to the first class. Glass, sealing-wax, silk, wood, and horny textures, are such bad conductors, that they are regarded as insulators or non-conductors. A partition or covering which consists of one of these substances will therefore protect other kinds of matter from a loss of electricity.

218. Every substance offers a certain resistance to the transit of electricity, but its amount varies greatly with the different kinds of matter. The metals possess the greatest conducting power; palladium standing highest, and quicksilver lowest. According to Pouillet's researches, if we take the conducting power of the latter as 1, iron will have 5 to 7, brass 2 to 9, copper 38·4, silver 51·5, and palladium 57.

The resistance offered to conduction by water and other liquids, exceeds beyond all proportion that of any of the metals. According to Weber, water at 32° conducts 180 millions of times, and at 99·86°, 101 millions of times, worse than quicksilver.

219. In respect of their conducting power, the human tissues may be regarded as warmed aqueous solutions. The resistance which they offer is thus less than that of pure water; but it is still so very considerable, that they will not bear the remotest comparison with the metals.

Lenz calculates, that if a man is brought into contact with the moistened brass handle of an electro-magnetic machine (such as will be hereafter described), his body offers the same resistance to conduction as would be presented by a copper wire, 71·58 miles long and 1-25th of an inch thick. Since the horny textures belong to the class of bad conductors, a wound of the integument at the surface of contact diminishes the obstacles to conduction.

220. The presence and direction of the electric current may be determined by the galvanometer. A very long copper wire is insulated by being wound round with silk, and it is then coiled around a rectangular frame, such as is shown at Fig. 41. Both its ends are left to project free. The elongated space in the interior of the coil contains an astatic

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magnetic needle, which is shown separately at Fig. 42. The term "astatic" is employed to designate an arrangement of two magnetic needles, in which the north pole of one is opposed to the south of the other,

FIG. 41.

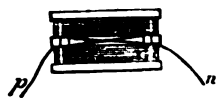
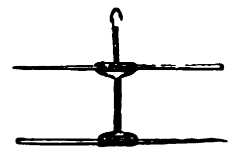


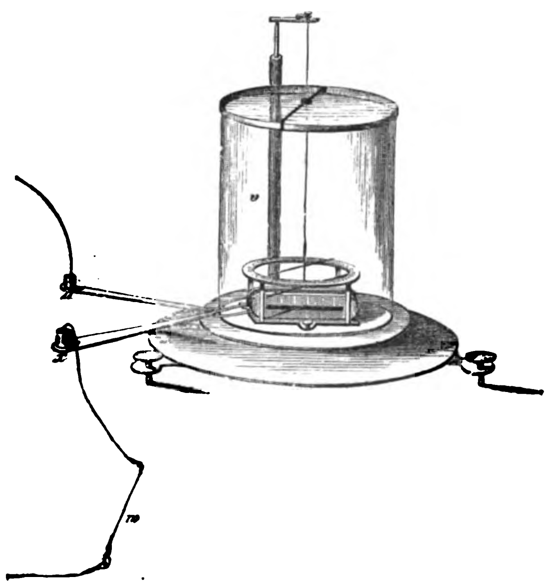
FIG. 42.



and *vice versâ*, as shown by the blunted and sharpened ends in Fig. 42. The use of this is, that it greatly diminishes the disturbances produced by the magnetism of the earth. The sensibility of the galvanometer depends upon the goodness of the needles, the ease with which they move, and the length of the copper wire. In the more delicate instruments, this is coiled from 18,000 to 22,000 times round the sides of the frame.

The complete galvanometer is shown in Fig. 43. The astatic pair of needles is suspended by a filament of raw silk, and the screw apparatus,

FIG. 43.



which is above, can raise or depress it. The upper needle plays over a circle divided into 360°, and the under is also free to move in the frame. A glass case, *v*, encloses the whole instrument, and protects it from disturbing currents of air.

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Let us suppose that the astatic needles, which rest in the magnetic meridian, were so arranged, that one end of the upper one stood at zero. If we now connect the mercurial cups, *x* and *u* (which are continuous with the ends of the wires, *p* and *n* Fig. 41), with a galvanic battery, the electrical current passes through the coil of wire, and causes the needles to deviate in a certain direction. For instance, suppose *x* connected with the positive, and *u* with the negative pole, so that the stream takes a course from *x* to *u*, we get a deviation of + 20°. But if we now change the poles, so that the current goes from *u* towards *x*, other circumstances being equal, the needle will swing to 340°, *i.e.*, to − 20°. We are thus enabled to determine the direction of the current, and from hence the nature of the electromotors. That is, we see which of them is positive, and which negative.

221. The deviation of the galvanometer needle does not increase in proportion with the strength of the current. In order to determine this proportion more exactly, we have to make use of the tangential compass. In the results which are furnished by this apparatus the force of the current is nearly proportional to the sine or tangent of the angle of deviation.

FIG. 44.

The arrangement of such a tangential compass is shown in Fig. 44. The current passes through a broad brass ring, *o*, the median plane of which is placed in the magnetic meridian. The simple magnetic needle, which is capable of being fixed or set free by the action of a screw, plays on a corresponding arc of a circle.

222. An experiment which is easily performed by means of this instrument immediately refutes an assumption, formerly very widely accepted. We shall hereafter see that the nerves are extremely susceptible to the galvanic current. As a consequence of this fact it was presumed that they were good conductors of electricity. But experience shows the reverse; and even theoretically, we may deduce the same conclusion from their composition, as they consist of oily matters and watery organic compounds.

Let us imagine that we had a galvanic battery in whose circuit was interposed a copper wire, of equal length and thickness with the nerve to be examined; and that the tangent galvanometer offered a deviation of 89·59° at the end of the arc. If we now exchange this wire for a similar piece of nerve, the needle will give no result, on account of the

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excessive obstacle to conduction which the nerve offers. And even supposing it to conduct twenty times better at this temperature than water at 33·08°, we might calculate that the deviation of the needle, even when all secondary impediments are removed, cannot amount to a second of a degree, since the conducting power of copper exceeds that of water at this temperature by 6,849,000,000 times.

Matteucci concludes from his experiments that muscle conducts electricity four times as well as either nerve or brain.

223. Let *a b* (Fig 45) be an artificial transverse section of a striated muscular fibre, suppose from the gastrocnemius; let *a c* be its longitudinal surface, and *c d* that natural tranverse surface to which the tendinous fibres are fixed. The observations made by means of the galvanometer teach us, that the longitudinal surface *a c* is usually positive with respect to the artificial or natural transverse section *a b* or *c d*. A connection like that shown by the dotted line, will produce a current

FIG. 45.

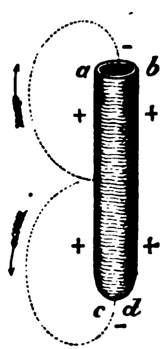
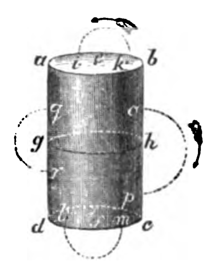


FIG. 46.



which goes from the positive longitudinal surface to the negative transverse one, *a b* or *c d*, in the direction of the arrows at *a c*. Let us imagine *a b c d* (Fig. 46) to be a perfectly cylindrical muscle, and that *e* and *f* form the centres of the circular transverse surfaces *a b* and *c d*, while the length of the cylinder is halved into *a d* and *b c* at *g h*. According to Du Bois every connection which unites two unsymmetrical points of the same or a similar surface produces a weaker current than those which proceed from the transverse and longitudinal surfaces together. If *i* lies nearer to the centre *e*, of the tranverse circle *a b*, the current passes from *k* towards *i*; on the other hand, if the point *p*, on the longitudinal surface, is further from *g h* than *o*, the current takes the reverse course from *o* to *p*. If *l* and *m*, or *q* and *r*, are at equal distances from the middle points *f* and *g h*, the magnetic needle of the interposed galvanometer remains at rest. Du Bois presumes, that the transversely-striated muscular fibre consists of molecules, with a peripolar arrangement, such

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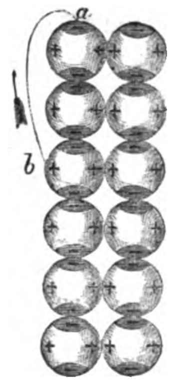
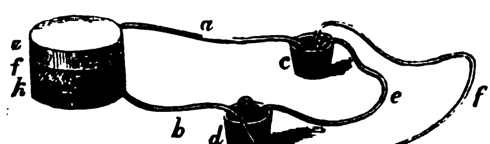
as is indicated by the diagram, Fig. 47. Each atom would thus contain a positive equatorial zone, and two negative polar ones. Their two axes are in two uninterrupted lines, which correspond to the long axis and the transverse section of the muscle.

FIG. 47.



224. Suppose *z k f*, Fig. 48, were a galvanic pile, consisting of a positive zinc plate, *z*, a moistened conductor, *f*, and a negative copper-plate, *k*: and that its poles, *a* and *b*, dipped into two cups of mercury, *c* and *d*, into which were also inserted two wires of equal thickness, *e* and *f*, so as to close the circuit. The shorter one, *e*, is the chief, and the longer, *f*, the secondary, conductor which closes the circuit. The chief current passes through *e*, because the resistance to conduction is diminished by the lesser length of this wire. But, on the other hand, *f* receives a supplementary current. Hence the presence of *f* to some extent weakens the current at *e*: for if *f* were not present, *e* would have taken up all the current. And by inter-

FIG. 48.



posing a galvanometer at *f*, we shall find that it only indicates a part of the current developed by *z*, *f*, *k*.

225. Something similar to this is seen when the electricity of the animal textures is tested by means of a galvanometer. The nutritional fluid, which moistens all the tissues, connects the opposite electrical poles, as shown in Fig. 47. And any second communication which we artificially interpose can only produce a secondary and more devious current. So that the result furnished by the galvanometer is only an exponent of the partial current;—only a fraction of the electrical excitement which the molecules of the muscle actually present.

226. According to Du Bois, the electrical opposition of transverse and longitudinal surface which occurs in the muscles, and is usually called the muscular current, also exists in the nerves. Matteucci found something very similar in the lungs, liver, and kidneys; and Du Bois also detected it in the nervous centres, the unstriped muscular fibres, and many other parts.

227. The variously directed currents which are generally produced

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by the muscular and other different tissues of the animal, unite to furnish a total effect, which has been called the proper or specific current. It takes for the most part a centripetal or ascending direction; —*i. e.* in the beheaded frog, it passes from the toes to the anterior extremity of the mouth.

228. If we allow a pair of galvanic plates to act upon any part of an animal, it is important to discriminate whether, besides this, they are also connected by any moist conductor. Let us suppose that *a b*, Fig. 49, is the sciatic nerve of an animal; *a* being the end nearest to the spinal chord, and *b* the peripheric extremity which is next to the muscles of the lower part of the thigh. A stream which passes in the nerve from *a* towards *b*, is called peripheric, centrifugal, or descending (Fig. 49); but if its path lies in the reverse direction, from *b* to *a* (Fig. 50), it is named central, centripetal, or ascending.

FIG. 49.

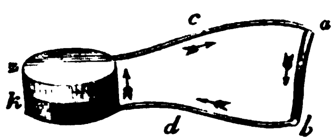
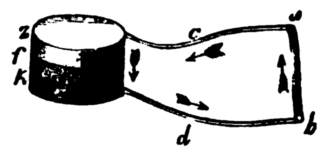
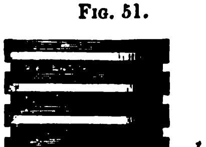


FIG. 50.



229. Supposing we take a positive zinc and a negative copper-plate, *z k*, (Fig. 49,) in the dry state, and connect them by corresponding wires with the sciatic nerve, *a b*, this will form their moist conductor. The positive stream goes from *z c* towards *a*, and from thence towards *b d k*; in one word, it is peripheric. The positive zinc extremity, *a*, also corresponds to the positive point of the nervous trunk. But if, on the other hand, we place a moist conductor, *f* (Fig. 50), between the zinc and copper-plate, the nerve *a b* will represent only a portion of the arch *c a b d* which closes the circuit. The positive current now passes in *z f k*, and from thence into *d b a c*; so that the nerve will be penetrated in the central direction; and its positive end, *b*, will correspond to the conductor of the negative copper, *k*.

FIG. 51.



230. If we make use of the ordinary galvanic column (Fig. 51), its activity undergoes a gradual but sensible diminution; so that the longer the time which has elapsed since the pile was built up, the weaker the current. A permanent pile in so far obviates this evil, that it maintains the current tolerably unaltered for a long time. The Bunsen's pile of charcoal and zinc, which is represented in perpendicular section by Fig. 52, forms a constant apparatus of this kind. In *a c*, Fig. 58, we are presented with a general view of the same apparatus.

A glass vessel, *a b c d*, contains a zinc cylinder, *e f g h*, which is split

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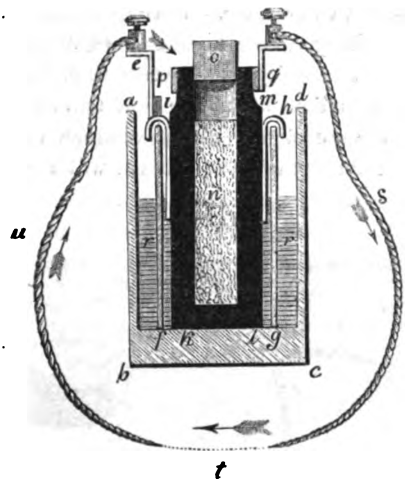
up in the direction of its length. A cylinder of charcoal, *i k l m*, is placed within this: its interior being hollowed out, and filled with fine sand, *n;* while above it is closed with a cork, *o*, and provided with a copper ring, *p q*.

FIG. 52.



The charcoal is nowhere in contact with the zinc: the separation of the two being secured by interposed glass rods. If the sand, *n*, be saturated with nitric acid and water, while a solution of salt, or dilute sulphuric acid, *r*, is poured into the glass vessel, *a b c d*, a tolerably constant current is produced. The porous charcoal allows a mutual diffusion between the nitric acid which occupies the interstices of the sandy particles, *n*, and the surrounding fluid, *r*. The positive current passes from the zinc, *e f*, through the moist conductor, *r*, towards the carbon, *i k*, and the copper ring, *p q*. Thence it passes out to the conducting wire, *s*, of the negative copper, *p q;* and returns through *u* to the zinc, *e f*. Thus we have here the same arrangement as that seen in Fig. 50.

231. We have seen (§ 187) that the particles of a vapour repel each other: so that it possesses a force of expansion or pressure, which increases with its density (§ 191), and by means of which it seeks to diffuse itself as widely as possible. The electric fluids resemble vapours in having a force of tension which is proportional to the square of their density. And in their passage through a body, its resistance to conduction only allows them to pass with the loss of a part of their tension and density.

232. If we close the circuit represented in Fig. 52 by the interposition of some conducting substance, *t*, its electric tension and density instantly rise, from zero, as high as the resistances to conduction will permit. And on opening the circuit the process is reversed; it returns to zero, unless, in the mean time, some of those phenomena of polarization have been

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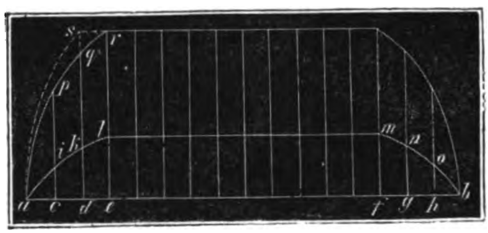
produced, which will hereafter be mentioned. And if the strength of the current is perfectly constant while the circuit is closed, the electrical density is maintained at the same height.

233. These phenomena may be represented by a diagram. Let *a b*, Fig. 53, be the time of the electrical operation, separated into a number of equal parts, *a c*, *c d*, *d e*, &c. If the ordinates, *c i*, *k d*, *e l*, which are placed perpendicularly to the abscisses, *a c*, *c d*, *e f*, indicate the densities of the passing electricity at the corresponding periods of time, these will be=0 at *a* and *b*: *i.e.* at the first and last instant of the experiment. If the closure of the circuit occupies the three portions of time, *a c*, *c d*, *d e*, the strength of the current will rise from *a* to *c i*, *d k*,

FIG. 53.



and *e l*. If we now draw a curved line—such as is called an equalizing curve—through the terminal points, *a i k l*, it will show the reciprocal conditions of the times occupied by, and the changes in the density of, the current. Supposing this latter were stronger than we have just imagined it to be, so as to amount to *c p*, *d q*, *e r*, we should get the steeper curve, *a p q r*. And if the process occupied a shorter period, so that *d s*=*e r* was already attained at the end of the second portion of time, *c d*, we should have the yet steeper curve, *a s*. The interruption of the circuit exhibits these circumstances in a reversed order. And if the current is constant during the closure of the circuit, it would be indicated by the straight line, *l m*; since the densities of the current would be equal at all periods of time.

In studying the nerves we shall see that they obey these adjusting curves much sooner than do the uniform currents of the electric fluids; hence we frequently find that the muscles contract at the instants of closing and breaking the circuit, so as to correspond to *a i k l* and *m n o b*, while during the closure they remain at rest from *l* to *m*.

234. When two electromotors come into mutual contact, the two opposed electricities are thereby set free; and if we connect a positive and a negative point by a conductor which allows a passage to the electricity, the quantity which can circulate depends on two collateral circumstances. The tension of the freed electricity, which is determined by its density, furnishes a force of pressure tending to impel it through

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the substance which closes the circuit. But the resistance which this offers determines the amount of impulsive force that really comes into use. Hence it is the quotient of the tension and the resistance to conduction that determines the strength of the current, or the amount of the electric fluids actually set in motion.

235. Supposing we take the simple circuit, *z f k*, Fig. 50, the electricity which passes from the zinc, *z*, to the copper, *k*, has to vanquish the proportionally great resistance offered by the moist pasteboard disc. If the copper wire which closes the circle, *c a b d*, is a short and thick one, the resistance which it offers to conduction is indefinitely small, compared with that of *f* (§ 218). Hence the strength of the current in such a single apparatus may be regarded as depending solely on the tension, and on the resistance which the moist disc *f* offers. But if *a b* be a piece of nerve, the amount of circulating electricity is considerably diminished.

236. If the substance *d b a c*, which closes the circuit, be a wire that offers no appreciable resistance in comparison with that of the fluid, *f*, between the zinc, *z*, and the copper, *k*—it will follow that a galvanic pile cannot furnish a stronger current than a simple element of equal transverse section. For if we increase the number of pairs of plates, we also increase the electrical tension. But as each of these has a similar moist conductor, the sum of the resistances they offer is increased in exactly the same proportion. Hence the quantity of current electricity remains the same.

237. But if, on the other hand, *a b* is a piece of nerve, or any other substance the resistance of which is considerable in comparison with that of the pile, the case is very much altered. Since the current force is the quotient of the tension by the sum of all the resistances to conduction (§ 234), it is obvious that the galvanic pile offers a considerable advantage. For the quantity of current force is here the sum of two fractions, the tension divided by the resistances of the pile, and the same tension divided by the resistances of the substance which completes the circuit. The first of these fractions remains the same as for the simple circuit, since tension and resistance are increased in the same proportion. But since the tension of the latter fraction is increased, while its resistance remains the same, it follows, that the galvanic pile furnishes us with a stronger current than a simple circuit of the same kind, whenever the resistance of the substance closing it is at all comparable with that of the pile itself.

238. The resistance offered to conduction by any particular mass varies directly as its length, and inversely as its thickness. Hence a short and thick wire allows of the passage of more current electricity than a longer and thinner one. But on account of its greater resistance, the latter presupposes a greater intensity or higher tension. And since this greatly assists in the production of physiological phenomena, we always

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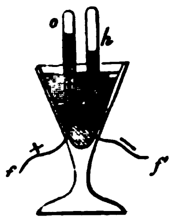
select long and thin wires for an apparatus which is intended to act energetically on the animal organism.

239. If the poles of a battery, *f* and *f'*, Fig. 54, are placed in two tubes filled with water and inverted with their open mouths in the same fluid, oxygen collects at the positive, and hydrogen at the negative, pole.

Fig. 54.



The nature of this electrolysis or electrical decomposition varies with that of the combinations in which it is produced. The bases of the oxides and salts go to the negative pole, and the oxygen of these compounds, as well as the chlorine, iodine, bromine, or acids of the salts, passes to the positive wire:—if not interfered with by secondary processes. Thus if the positive pole consists of zinc, it is oxidized at the expense of the oxygen there set free. Or if the electrodes operate on a solution of ammonia, the oxygen of the decomposed water unites with the hydrogen of the ammonia, so that its nitrogen is set free. But in all these cases, the amount of electrolysis depends on the strength of the current which passes through the fluid.

240. When the two electrodes, *f* and *f'*, Fig. 54, dip into water, each becomes covered with a stratum of the gases decomposed. They are thus polarized: *i.e.* the products of electrolysis which cling to their surfaces produce a current, which is in the opposite direction to the original one, and goes from *f* towards *f'*. If *f* becomes covered with oxygen it follows, that the positive pole, *f*, attracts the oxygen in itself negative, and sets the positive hydrogen free. Hence this polarization has its negative element at *f*, and its positive one at *f'*; which is exactly the reverse of their position in the original current. And even in the case of a single pair of plates, the products of decomposition are similarly separated; so as to weaken the original galvanic current in the same way. And thus, if it has to traverse an additional fluid, it must not only overcome the resistance this offers to its conduction, but also a certain resistance to transit, which is dependent on the disturbance offered by this polarization.

241. If the electrodes, *b b*, of the column, *a*, Fig. 55, dip into two vessels, *c c*, filled with water or some other decomposable fluid, they, as well as the wire, *d*, which closes the circuit, may be polarized. If after some time *d* be taken out, dried, and applied to a living nerve, the corresponding muscles not unfrequently contract, in consequence of *d* possessing a positive and a negative end, which respectively correspond to the opposite poles of the original battery. If, instead of the wire and the fluid, a nerve, *d*, be interposed between the electrodes, *b b*, the same phenomena of polarization may obtain. They form a necessary condition of proper electromotive force, and of a great resistance to transfer, such as is offered by the interposed animal tissue.

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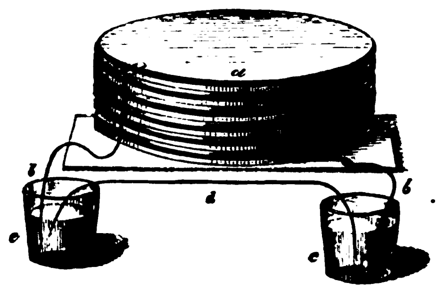
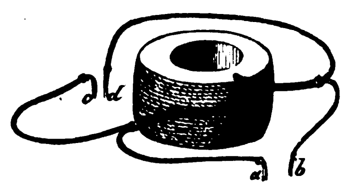
242. The phenomena of electrical induction are extremely important in a physiological point of view. We shall hereafter see that they offer many points of resemblance to the functions of innervation. And the inductive current acts with especial energy on the nerves and muscles of the living body.

FIG. 55.



243. Suppose two conducting wires to be wound round with silk, and coiled around a wooden cylinder, as shown in Fig. 56, where *a b* exhibits the free extremities of one wire, and *c d* those of the other. The interposition of a short piece converts *c* and *d* into a closed spiral. The connection of a galvanic circuit with *a* and *b* establishes a current through this wire, which lasts as long as electromotive force is developed in the battery. But the second wire, *c d*, offers very different phenomena: on completing or breaking the previous circuit, an electrical current is developed, which is hence called the induced current. But as long as the first circuit is complete, or after this is interrupted, it is altogether absent.

FIG. 56.



244. Hence the essential feature of induction is, that a wire which closes a circuit, and gives passage to a current, excites a current in another isolated wire in its immediate neighbourhood, at the instant of closing or breaking that circuit. That forming the circuit is hence called the inductive,* and the other the inducteous, wire; and the same terms are applied to the corresponding currents themselves.

245. If the inductive current flows in the direction from *a* to *b*, the inducteous, which begins at the moment the circuit is closed, takes the opposite course from *d* to *c*. The act of opening the circuit induces a

* These are also often less accurately named the inducing and induced currents. The Editor takes this opportunity of remarking that he has generally adopted the admirable nomenclature of electricity used by the late Prof. Daniell, in his "Introduction to Chemical Philosophy."

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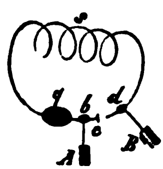
reverse current, which has the same course as that formerly taken in the closed circuit, or from *c* to *d*.

246. If *c d* is a long and thin wire, while *a b* is a short and thick one, this condition will give the first a higher intensity, the second a greater power (§ 238). Hence the corresponding curve (§ 232), and the physiological effect of *c d*, will be increased. On this account, long and thin wires are selected for an apparatus which is intended to act strongly on the living nerves.

247. We will now suppose a very long thin conducting wire to be wound round with silk, and coiled closely around a wooden reel. If such a wire be connected with a galvanic battery, its coils are capable of mutual induction. The accompanying diagram will explain the way in which this fact is taken advantage of in many forms of the electro-magnetic apparatus which will hereafter be described. Let *q* be a galvanic battery connected with the helix of wire; the coils in the neighbourhood of *s* will produce phenomena of induction. By pressing the end of the wire *c* against the opposite one *d*, the circuit is closed. And the current of induction which arises at this moment passes almost exclusively in *q s d c b*, even when the metallic handles, *A* and *B*, are grasped with moistened hands. For not only does *q s d c b* form a shorter path than the human body which connects *A* and *B*, but it offers a comparatively smaller obstacle to conduction. But on the other hand when *c* is removed, as shown in the figure, the opening of the circuit induces a current in the opposite direction, which necessarily passes through the human body present in this situation, because it forms a part of the only closed circuit which now exists; viz., *q s d B A b q*. Hence this apparatus only gives the impulse which arises when the circuit is broken, and not that which occurs on its closure.

FIG. 57.



248. These preliminary considerations may suffice to explain the action of the electro-magnetic apparatus. An apparatus of this kind, adapted to medical and physiological purposes, is represented at Fig. 58. Since *c* is the zinc cylinder of a Bunsen's (§ 230) element, while *a* is the copper ring connected with the charcoal cylinder, *b* is the positive and *d* the negative pole (§ 229). The box also contains either a short and thick inductive wire which is connected with these poles, and an inducteous coil of long and thin wire, or a single long wire, the coils of which act inductively upon each other.

However this may be, the whole is so arranged, that the current proceeding from *b* passes successively through *i*, the support *h*, the hammer *g*, the piece of brass *F*, and the other conducting wire *d*. It is evident that the circuit is only complete so long as the metallic hammer *g* touches the metallic support *h*. If *g* be raised from *h*, the circuit is

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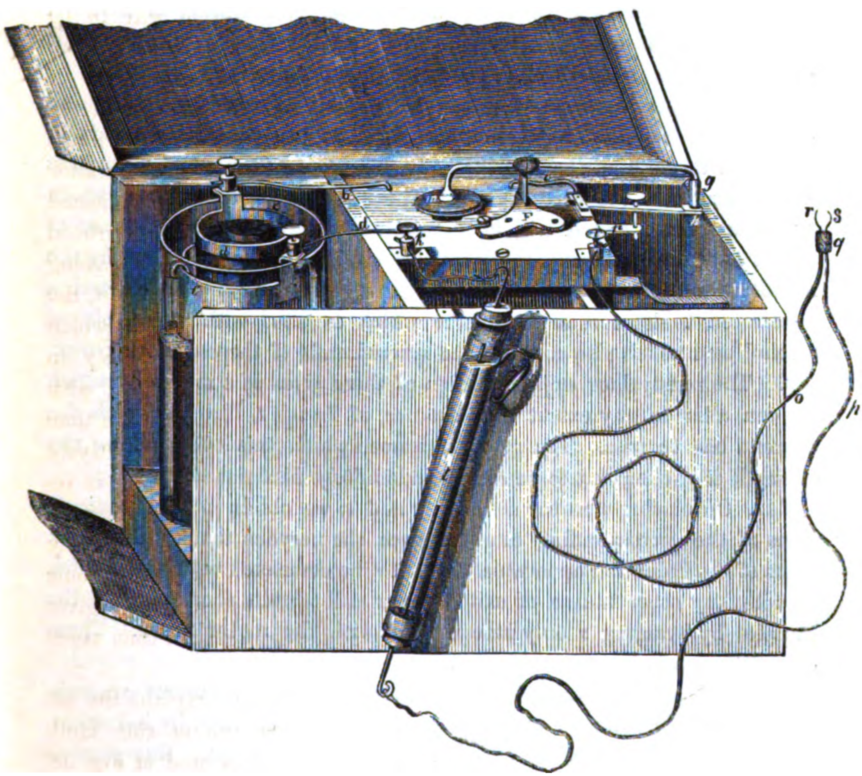
broken. A lever with two arms, which plays upon an upright elastic metal plate, and whose longer arm sustains the hammer *g*, bears at the end of its shorter arm a plate *m*, bound with iron. At some distance from this is a piece of iron, or a bundle of iron wires, which occupies the interior of the wooden reel around which the inductive coils are wound. When the circuit is completed, this iron becomes magnetic, so as to draw

FIG. 58.



downwards the iron-bound plate *m*. The hammer *g* then rises from its support *h*, and breaks the circuit. This again causes the iron in the coil to lose its magnetic power. The plate *m* therefore ceases to be attracted, the hammer *g* descends on its support *h*, and the process recommences. In this way a continual hammering is produced, which corresponds with a perpetual shutting and opening of the circuit, and thus at the same time produces corresponding inducteous currents.

Other circumstances being equal, the time which elapses between a completion and an interruption of the circuit, will depend upon the distance through which *m* and *g* have to pass. The screw at *p* raises or

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depresses *h*, and hence, if *m* be similarly depressed, it increases or diminishes the distance from *g* to *h*. In the first case we should get a smaller, in the second a greater, number of inducteous currents in the same period of time.

The two projections, *k* and *l*, in which other wires or handles may be fixed, are connected with the inducteous coil, when an inducing and inducteous wire are both present. The currents of induction, therefore, always pass through the human body. But if the apparatus has only one spiral, *k* and *l* answer to the points *A* and *B* indicated in Fig. 57. Hence here it is only the breaking, and not the closing, of the circuit which sends a current through the person connecting them. (§ 247.)

If the copper wires *o* and *p* are immediately attached to *k* and *l*, and united, but insulated by sealing-wax at *q*, we can pass the currents of induction through any part of the body, by means of the metallic surfaces which terminate the wires at *r s*. The strength of the current which proceeds from *b* and *d* will be determined solely by the resistance of the part, and the incomparably smaller obstacle which is offered by the metallic wire. But should it be too strong for our purpose, we add a moderator, *t*. This is a glass tube which is filled with water, oil, or alcohol, and which also contains the severed ends of the conducting wire, *k p*. The removal or approximation of these gives us a means by which we can alter to any extent the distance of liquid, *t*, through which the current has to pass. The great resistance which this offers allows the strength of the current to be almost indefinitely diminished.

249. On placing a motor nerve at *r* and *s*, we obtain bipolar contractions of the corresponding muscles, since the nervous trunk unites both poles of the induction apparatus. But if *r* be connected with the ground, or with any other means of exit, we can still obtain shortening of the muscles by bringing *s* only into contact with the motor nerve. These contractions are, however, unipolar.

250. The exciting current of the electro-magnetic apparatus proceeds from a galvanic battery: so that one electric current leads, by induction, to a second, which may be called an electro-electric one. But just as the current circulating in the inductive coil magnetizes the iron contained in its interior, and converts this, for the time, into an electro-magnet, so an alteration in the condition of an ordinary magnet may cause currents of electricity by induction. The operation of the rotary magneto-electric machine depends on this fact.

251. Suppose *a b* (Fig. 59) is a strong horse-shoe magnet, and *m c n* a piece of soft iron of similar shape, around which is wound a properly prepared coil of wire. The interposition of a fit connecting substance between the two ends of this wire will show that a current is induced in it at the instant of opposing or separating *m n* and *a b*. But as long as the soft iron remains attached to the magnet, no such current obtains. The two

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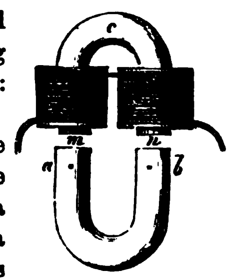
currents of induction which accompany the closure and removal of iron pass in opposite directions. And since it is a change of magnetic condition which causes the induction of the electrical current, it is called a magneto-electric induction.

252. When the wheel of the machine is turned the bar and coil revolves, and is thus twice opposed to the magnet and twice removed from it, during each revolution. So that four currents are induced: two in each opposite direction.

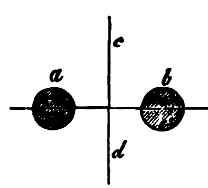
FIG. 59.



The curved soft iron which is surrounded by the helix is called the inductor. If the wire of the helix be short and thick, its current furnishes a great quantity of electricity: if long and thin, a great intensity. The cause of this difference has been already mentioned (§ 238). Other arrangements are often connected with this rotary machine, by means of which only the current induced on separation is retained: and this is sometimes adapted to the human body, like the single helix mentioned in § 247. The velocity of rotation of course determines the number of currents which are induced in an unit of time: so that a slower movement weakens the general effect, just like the depression of the supporter *h* (Fig. 58). And if we desire to reproduce the moderator *t*, we have only to introduce a bar of soft iron between the two poles of the magnet. This, by diminishing the magnetism of the excitor horse-shoe, also weakens the currents which are induced by the curved piece of soft iron opposed to it.

253. When a body is suspended between the two poles, *a* and *b*, Fig. 60, of a very strong electro-magnet, it may change its situation in one or two ways. If it belong to the class of magnetizable substances, it will be attracted whenever the closure of the circuit converts the horse-shoe into a magnet. Here it takes up an axial position, in the transverse line which unites *a b*. Those metals which may be magnetized under ordinary circumstances,—and some others, such as manganese, chromium, and platinum,—exhibit this kind of movement. But Faraday has discovered that if a substance possesses diamagnetic properties, it seeks to place itself equatorially;—*i.e.*, perpendicularly to the line connecting *a b*,—on account of its being repulsed by the poles of the magnet. A glass rod exhibits this second movement.

FIG. 60.



254. Since water belongs to the diamagnetic substances, we might *à priori* expect that the animal tissues containing it in such large proportion would also possess diamagnetic properties. Zantedeschi found that

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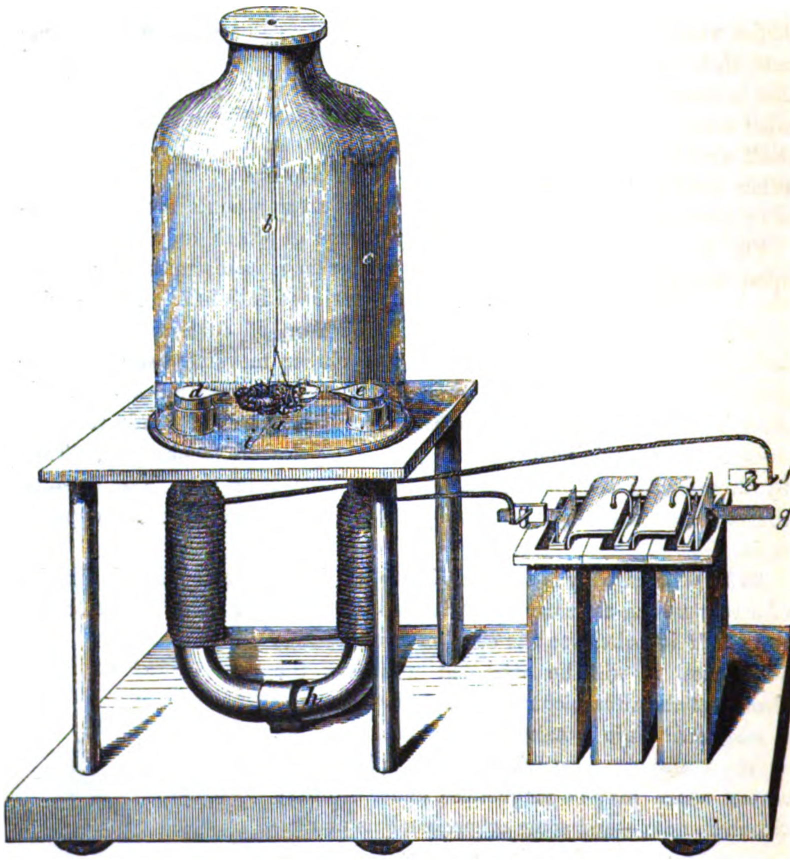
this was actually the case with the blood, bones, muscles, nerves, and ova. And De La Rive and Brunner have shown that, in the case of the frog, it holds good for the entire animal.

The apparatus made use of for this observation is exhibited in Fig. 61. The frog, properly confined by the ligatures, is suspended by a long filament of raw silk, *b*, so as to allow of its free rotation. All disturbing

FIG. 61.



currents of air are cut off by the inverted bell-glass. Let us suppose that in a state of rest the animal is arranged axially, as in Fig. 61. By connecting *f g* we close the circuit of the battery placed here, and convert the iron *h*, together with its pointed extremities, *d e*, into a magnet: under these circumstances the body of the animal rotates in the equatorial direction, *a i*. A very powerful electro-magnet is necessary to the success of this experiment.

255. The dried animal tissues have not hitherto been examined. It is

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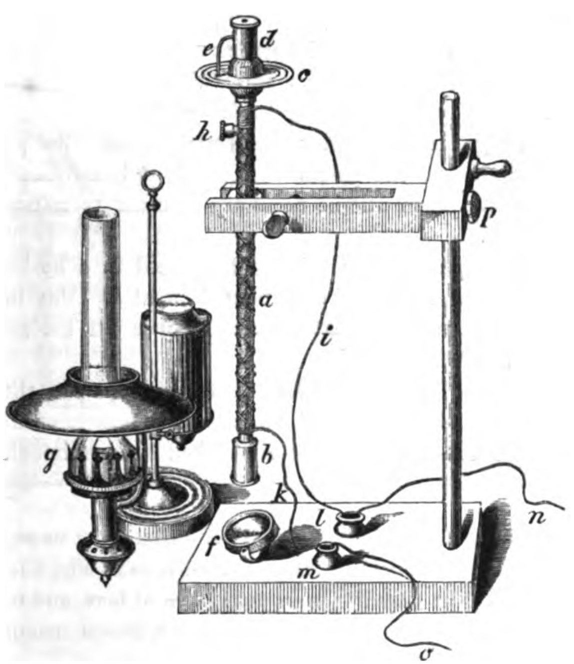
possible that those of them which contain a large proportion of iron might have a magnetic action, if the influence of this metal could be freed from that of the diamagnetic molecules by which it is usually overpowered. According to Pluecker, the single optical axis of a uniaxial crystal, and both axes of a binaxial one, exhibit the same repulsive or diamagnetic action. But at present there are no observations on this point which have reference to suitable vegetable or animal tissues.

256. When luminous rays take an axial direction through certain bodies which are placed between the poles of very powerful electro-magnets, their planes of polarization are rotated. The direction of the rotation corresponds with that which the positive electrical current of a coil must take, in order to communicate to soft iron the same polarity which itself would exhibit towards an electro-magnet. Water, alcohol, oil, and æther exhibit this rotation. In many doubly refracting substances, such as calcareous spar and sulphate of lime, it is absent.

Fig. 62 represents an apparatus which may be used in observations upon this fact, and on the circular polarization of fluids. The brass

FIG. 62.



tube, *a* (which, for the sake of distinctness, is drawn much too long), is closed below by a stopper, which encloses a glass plate. On this slides *f*, which contains a Nicol's prism (Fig. 33, p. 58). The upper end of *a* has

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a second stopper, which carries a disc divided into 360 degrees, and a piece, *d*, which is provided with a second Nicol's prism. The index, *e*, defines the rotation which is given by the experimenter to *d*. The moveable mirror, *f*, reflects the rays of light which come from the lamp *g* through *b a d*. And on looking through the upper aperture at *d*, we get the greatest brightness when the planes of polarization in the two prisms are parallel to each other, or the deepest obscurity when they cross at a right angle (§ 172).

We now remove the stopper from the short side tube *h*, and place the upper prism at the point of greatest darkness. We next fill the tube by means of a pipette with the liquid to be examined—whether it be a solution of sugar, or albumen, or filtered and diluted bile, or the urine of a diabetic or albuminuric patient. And we now find that, in order to reattain the point of greatest obscurity, it is necessary to turn *d* through an angle, the amount of which is indicated by *e*.

The whole length of the tube *a* is covered with a very long copper wire, which is wound around with silk, and dips by its two ends into the quicksilver cups, *l* and *m*. If the poles of a battery, *n* and *o*, be also sunk into these cups, the plane of polarization undergoes a fresh displacement. This result may be artificially exaggerated. For if the stream passes from *i* to *k*, it will turn round the plane of polarization to a definite extent in one direction; and if from *k* to *i*, of course in the reverse one. Now by first directing the current from *k* to *i*, and setting the prism at its greatest obscurity, and then reversing the poles of the battery, so that the current passes from *i* to *k*, it is obvious that twice the rotation of the prism will be necessary in order to re-establish this greatest obscurity.

The screw at *p* permits the tube to be placed in a horizontal position, so as to allow of fluids being poured in at *h*. But the upright position has this advantage, that we can at once fill the tube to any amount we like.

257. Hitherto the influence of electrical currents upon the polarization of organized solids—such as starch granules, muscle or nerve fibre, or the crystalline lens—has not been established by experiment.

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CHAPTER V.

CHEMICAL COMPOSITION OF ORGANIZED BEINGS.

258. There is not a single element of the different animal and vegetable tissues which may not also be found in the inorganic world. The edifice of nature is constructed with materials which are everywhere present. And hence it is to secondary causes—to meteorological circumstances, and to their more composite food—that we must look for the reasons why different creatures inhabit tropical or arctic countries, higher or lower regions—why beings that live and thrive in the elastic fluid atmosphere which surrounds the earth, perish in the liquid medium of its waters—or why the inhabitants of this latter cease to exist in the air.

259. The elements most frequently found in the animal body are oxygen, hydrogen, carbon, nitrogen, sulphur, phosphorus, chlorine, silicon, fluorine, potassium, sodium, calcium, magnesium, iron, and manganese. Normal or abnormal peculiarities of diet may introduce iodine, bromine, aluminium, copper, arsenic, mercury, and many other metals. But most of the remaining elements have never yet been found in any part of an organized being.

260. The gases of the animal body consist chiefly of oxygen, hydrogen, nitrogen, carbonic oxide, carbonic acid, carburetted hydrogen, phosphuretted hydrogen, and sulphuretted hydrogen. Infrequent secondary causes may give rise to the presence of other gases in the cavities of the body; either by generating them directly, or merely liberating them during the metamorphosis of the solid and fluid tissues. Chlorine, arseniuretted hydrogen, and other elastic fluids, are, under certain abnormal circumstances, retained in the cavities of our bodies.

261. Compounds which are easily volatilized at the temperature of the organism, are not unfrequently given off from it in the form of vapour. Thus ammonia, volatile fatty acids, hydrocyanic acid, alcohol, and æther, may pass off at the free surfaces of the lungs and skin, in the form of elastic fluids. It is important to bear in mind, that the great difference between the tension of these vapours and that of water is capable of altering the eudiometric condition of the respiratory air (§ 187).

262. If an organic compound he exposed to the influence of a high temperature, in a medium which is rich in oxygen, its entire mass will, under the most favourable circumstances, pass off in the gaseous form.

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Hence such a body consists of none but volatile constituents. On the other hand, many substances leave behind them an ash: *i.e.* a series of fixed compounds, which were formerly mixed with the volatile ones.

263. If in this experiment a number of dissimilar tissues are made use of, some of them may possibly consist of volatile substances only, while others are composed of both volatile and fixed elements. The oily content of the fat-cells is completely driven off at a high temperature. On the other hand, the substances which form their walls, and occupy their interstices, leave an ashy residuum. But if we burn a tissue of more uniform texture, which originally contained both kinds of constituents, we find the ash equally divided through the whole or the greater part of the texture. Thus a calcined thin section of bone, or even a spermatozoon which has been treated in the same way, exhibits to a microscopic examination the same form which it possessed in the fresh state. And if the greater part of the substances which form the ash of bone are removed by the action of dilute muriatic acid, the cartilage which remains still possesses the Haversian canals, laminæ, and lacunæ, which are visible in the recent structure.

264. If we gradually increase the heat to which any organized substance is exposed in a highly oxygenated atmosphere, the first effect is to drive off the gases it contains, together with such of its combinations as are vaporized at comparatively low temperatures. The usual result of this process is complete exsiccation. If the heat be further increased, the mass is charred. Certain new combinations, called "empyreumatic," are produced. If the heat is carried yet further, the carbon of the organic matter present is converted into carbonic acid, and the hydrogen into water, the oxidation in both instances being accomplished at the expense of the oxygen at their disposal. The nitrogen is for the most part set free. But it may chance that a part of the carbon obstinately resists the metamorphosis into carbonic acid. And if, on this account, we expose the given body to a continuous red heat, it not unfrequently happens that particular constituents of the ash are volatilized; such as chloride of sodium, or the carbonic acid originally combined with the earths.

265. It is evident that these phenomena must exercise an important influence upon the numerical values which we deduce from such examinations. If we dry an organized body at 248°, the loss of weight has a reference, not merely to the water of imbibition which has been driven off, but also to those other volatile compounds which are unable to resist this degree of heat. Even if the whole forms a continuous and exsiccated mass, it often obstinately retains a certain quantity of water. If it has been powdered, and again dried, it often acts as a hygroscopic substance, in the interstices of the solid molecules of which the watery vapour of the atmosphere is condensed (§ 150). If it be weighed when too warm, conduction

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(§ 202) and radiation (§ 210) of heat may elongate the corresponding beam of the scale, and render inaccurate the determination of its weight. If it be allowed to cool, its weight gradually increases from the preceding cause. The solid residuum of the blood may illustrate all these sources of error.

266. If the organised substance contains no ashy constituents, of course no trace remains after burning it. If it contains fixed compounds, no dark discoloration ought to show a relic of carbon. If very strongly heated, it is easy to get too small an ash, since not only the ordinary volatile matters, but even portions of the fixed ones, are thus driven off.

267. We see that the determination of the amounts of water, volatile compounds, and ash, although apparently so simple, implies a considerable degree of uncertainty. And if we examine the remaining methods of experiment which chemistry makes use of, we shall find that they present, on an average, far more numerous sources of error than either of the two remaining means of research: viz., than either anatomical or physiological investigation. Part of the mischief lies in the very nature of the thing. But another part may certainly be obviated by more accurate methods of experiment.

268. Strictly speaking, it is only a careful micro-chemistry,—*i.e.* an union of microscopy with chemistry—which can accomplish what physiology requires. We operate upon the blood, a muscle, or any other part, as upon a whole, while we are in reality concerned with a number of the most different tissues. It is scarcely better than if we subjected to examination the entire mass of an animal, irrespectively of its several organs. The greater part of the tissues can, at best, only give a certain predominant indication in the results. The ideal of a chemical examination into the dissimilar organized substances is, that of a complete quantitative analysis of their different microscopic constituents. Except in some one or two instances, it is probable that this task will never be satisfactorily accomplished. All that we can at present do is to make qualitative investigations under the magnifying glass. And where particular compounds are secreted in the form of microscopic crystals, their shape sometimes affords a means of determining their nature. For instance, the usual forms of the crystals of chloride of sodium, are represented in Tab. I., Fig. I.; those of uric acid in Fig. II.; those of oxalate of lime in Fig. III.; and of those ammoniaco-phosphate of magnesia in Fig. XVII. *i k l.*

269. The volatile substances consist for the most part of oxygen, hydrogen, carbon, and nitrogen, or of the first three of these only. Hence they may be divided into azotized or quaternary, and non-azotized or ternary substances. Starch, the sugars, lactic acid, and the pure oils and fats, contain no nitrogen; but albumen, fibrin, casein, hæmatin, urea, uric acid, hippuric acid, and most of the other bodies which we meet with in the animal organism, belong to the class of azotized compounds.

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270. Ultimate or elementary analysis gives us the quantities of oxygen, hydrogen, carbon, and nitrogen, which are contained in the volatile constituents of an organic substance. We will first consider the simplest process :—the ultimate analysis of a non-azotized body which is devoid of an ash.

271. The first requirement of elementary analysis is, that the substance should contain no water, so that the hydrogen and oxygen may be given free of error. But since combustion in the atmosphere would leave a carbonaceous residuum, the pulverized substance is either mixed with other bodies, which give off oxygen at a red heat, or it is subjected to combustion in a current of this gas.

272. It was formerly the practice always to make use of an admixture of oxide of copper. But since, in spite of the oxygen thus imparted, many organic combinations—especially the animal tissues so difficult of combustion—leave a residue of carbonaceous particles, the chromate of lead is now substituted. But both of these substances have the disadvantage of offering no difference of colour by which any such residue of carbon may be betrayed. Hence it is safer to mix the powdered organic mass with finely-divided quartz, and burn it in a stream of oxygen gas, allowing any empyreumatic vapour which may be given off to pass through a stratum of powdered oxide of copper.

273. If sugar be completely burnt in this way, only water and carbonic acid are produced (§ 269), and if these elastic fluid compounds, expelled by heat, are made to pass through two tubes capable of completely taking them up, the gain of their respective weights will indicate the quantity of water and carbonic acid.

274. Chloride of calcium, and the sulphuric and phosphoric acids, possess the greatest power of retaining water. A tube filled with fragments of chloride of calcium, or a cylindrical tube having a globular dilatation, which contains filaments of asbestos steeped in sulphuric acid, will thus give the quantity of water. A solution of caustic alkali easily absorbs the carbonic acid, and may be immediately applied by means of a Liebig's potass apparatus. Or the same object may be yet more securely attained by filling a tube with slaked lime moistened with solution of potash, where the strong attraction of the former substance for carbonic acid greatly assists its absorption. But one circumstance must here be borne in mind. Since the tube for the absorption of water immediately follows the combustion tube, the carbonic acid which passes over to the lime is anhydrous; and if the ultimate analysis of a non-azotized substance be accurately made, all carbonic acid will be absorbed here. And hence no elastic fluid coming from the combustion of the organic compound, can pass any further. But if any of the oxygen given off from the oxide of copper or chromate of lead becomes free toward the end of the experiment, or if a continuous stream of oxygen be made use

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of, this gas will mechanically carry off some watery vapour in its transit through the moistened lime, so that the carbonic acid tube will be liable to a loss of weight. The danger of this error is altogether avoided by having immediately behind the tube a segment furnished with asbestos steeped in sulphuric acid.

275. If 3·861 grains of sugar of milk undergo combustion, we shall get 2·332 grains of water, and 5·606 grains of carbonic acid. Since the former of these two compounds contains 11·11 per cent by weight of hydrogen, and the latter 27·27 per cent carbon, the 3·861 grains sugar of milk contain ·2625 grains of hydrogen and 1·529 grains of carbon. The deficiency of 2·0695 grains is evidently the amount of oxygen which it contained. And calculating the percentage by weight of each of these, we obtain 6·8 per cent hydrogen, 39·6 carbon, and 53·6 oxygen.

276. If the substance belongs to the class of azotized compounds, we find the carbon and hydrogen as before: and the amount of nitrogen is then determined by a second analysis. The residue again determines the amount of oxygen; or of this and any other additional constituents.

277. In the ordinary mode of combustion, the nitrogen is set free in the gaseous form. Hence it was formerly collected over mercury, and its weight then reduced from its volume at the existing temperature (§ 195) and pressure (§ 68). But the numerous sources of error to which these and all other determinations of bulk are liable, have latterly induced chemists to attempt its direct estimate by weight. If an azotized compound be raised to a red heat with caustic lime which has been slaked with soda lye, the nitrogen seizes on the hydrogen of part of the water present, to form ammonia. This passing into a receiver of dilute hydrochloric acid, is completely taken up, and converted into hydrochlorate of ammonia. If we treat this fluid with chloride of platinum, and a mixture of alcohol and æther, the whole is precipitated as ammonio-chloride of platinum. At a red heat, this is reduced to pure platinum. And since 100 parts of this correspond to 6·31 by weight of nitrogen, we thus find out how much was contained in the organic substance. Finally, reducing the carbon, hydrogen, and nitrogen to parts per cent, the residue again gives the oxygen of the volatile constituents.

278. Most of the elementary analyses hitherto made are liable to errors greater than any presented by modern eudiometric researches on the different gases. A gaseous mixture containing watery vapour, nitrogen, oxygen, and carbonic acid, may be analysed so accurately that the amount of each constituent in two results differs at most by only 1—2½ tenths per cent; and often by less than this in repeated examinations. While two ultimate analyses of the same non-azotized substance not unfrequently exhibit differences of 4 to 8 tenths in the percentages of the carbon and hydrogen. And since a great number of the analyses hitherto made of the azotized compounds are founded on the determina-

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tion of the nitrogen by volume, we find very considerable differences in this substance also.

279. But the chemist has not only to inquire into the percentage composition of a substance: he has also to determine its atomic weight and its chemical formula. And organic chemistry is much more frequently thwarted in this attempt, than inorganic.

280. If we take the atomic weight of oxygen at 100, that of carbon amounts to 75, and hydrogen 12·5. Now, if sugar of milk contains 39·6 per cent of carbon, 6·8 hydrogen, and 53·6 oxygen, the proportions will be $39{\cdot}6 \div 75 = {\cdot}528$ atoms of carbon; $6{\cdot}8 \div 12{\cdot}5 = {\cdot}544$, atoms of hydrogen; $53{\cdot}6 \div 100 = {\cdot}536$ atoms of oxygen. If these fractions be reduced to their approximative whole numbers—if, for instance, we strike off the two last places of decimals, and double the magnitude ·5,—we get one atom of carbon, one of hydrogen, and one of oxygen. Hence assuming that 75 parts by weight of carbon, 12·5 hydrogen, and 100 of oxygen, were united to form sugar of milk, this would give a total of 187·5. And if we check this result by reducing such a composition to parts per cent, we get 40 per cent carbon, 6·67 hydrogen, and 53·33 oxygen; a result sufficiently near to that obtained by analysis. Hence we may provisionally assume that the formula for sugar of milk is $C_1H_1O_1$, and its atomic weight 187·5.

281. It is evident that the mutual relations of the constituents are no way changed when we multiply all the atoms of a formula — and hence the atomic weight also—by the same number. Thus, supposing sugar of milk to consist of $C_{12}H_{12}O_{12}$, instead of $C_1H_1O_1$, it will then contain $12 \times 75 = 900$ parts by weight of carbon, $12 \times 12{\cdot}5 = 150$ hydrogen, and $12 \times 100 = 1200$ oxygen, united into a total of $12 \times 187{\cdot}5 = 2250$. And since there is an indefinite number of such multiples, it is obvious that mere ultimate analysis is insufficient to show what is the formula and atomic weight of a compound.

282. In favourable instances, this deficiency is supplied by observing the decomposition of its salts, or by determining its capacity of saturation. But since the latter has hitherto not been determined for sugar of milk, we are at present unable to say what formula ought to be ascribed to it. Some circumstances exhibited by kindred substances, which will hereafter be mentioned, at most only allow us a preference of the expression $C_{12}H_{12}O_{12}$.

The lactic acid into which sugar is frequently transformed behaves very differently. Its elementary analysis gives a composition of 44·3 per cent carbon, 6·12 hydrogen, and 49·58 oxygen. This closely corresponds to the formula $C_6H_5O_5$, and the atomic weight 1012·5. But since sugar of milk seems to be $C_{12}H_{12}O_{12}$, we might imagine that $C_{12}H_{10}O_{10}$, and 2025 were respectively the formula and atomic weight of the kindred lactic acid. But an examination of its salts affords us decisive facts.

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Suppose 100 parts of lactate of baryta (BaO $\overline{L}$), furnished, when mixed with sulphuric acid, 74·037 of sulphate of baryta; ($BaO{\cdot}SO_3$) it follows that the atomic weight of the former salt amounts to 157. For since that of sulphuric acid is 40, and that of baryta 76, that of the sulphate of baryta will be 116. And thus, as 74·037 : 100 : : 116 : 157. The atomic weight of lactic acid is therefore $157-76=81$, which agrees with the formula $C_6H_5O_5$; and 100 parts of lactate of baryta will yield 51·5 lactic acid, and 48·5 baryta.

Supposing that we expose 1544·4 grains of urea to a stream of dry hydrochloric acid gas, and so get 2476·6 grains of dry hydrochlorate of urea, it follows that, taking the atomic weight of hydrochloric acid at 36, that of urea amounts to 60. This corresponds to $C_2H_2N_4O_2$.

283. Hitherto it has been impossible to find the saturative capacity of many organic compounds: or to apply other tests which are often useful in determining the true formula of a substance;—such as the combination of its products of decomposition, or the weight of its vapour. On this account, all conclusions respecting their composition are devoid of a sure basis. It is impossible to decide how far any approximative formula which has been assumed for them is correct; or whether their true atomic numbers are larger or smaller. And a more careful examination generally teaches, that, even in cases to which these observations are inapplicable, the ground is less secure than appears at first sight.

284. It was formerly supposed that the atomic weight of carbon was 6·115, and not 6. It was believed that the equivalent of one atom of hydrogen was ·5, and consequently that of two atoms 1·; while at present the latter whole number is preferred. And it is very possible that the alteration of these numbers may exert an important influence on the number of atoms of carbon, which are ascribed to an organic compound. And since the formulæ of organic chemistry are alternately based on old and new calculations, we have here a cause of those differences, which can only be obviated by accurately testing the particular equivalents found in elementary analysis.

285. The small atomic weight of hydrogen leads to another disadvantage. Wherever the capacity of saturation of the entire compound remains undetermined, and the atomic weight which has been assumed from its simplest relations is a large one—there the variations which elementary analyses offer will leave the number of atoms of this element uncertain. This will be better shown by example.

Suppose an analysis of albumen yielded 53·54 per cent of carbon, 7·22 hydrogen, 15·74 nitrogen, and 23·7 oxygen: we obtain from this $53{\cdot}54 \div 6 = 8{\cdot}923$ for the carbon, $7{\cdot}22 \div 1 = 7{\cdot}22$ for the hydrogen, $15{\cdot}74 \div 14 = 1{\cdot}12$ for the nitrogen, and $23{\cdot}7 \div 8 = 2{\cdot}96$ for the oxygen. If we assume the atomic weight of albumen to be a very high one, and take in the first place of decimals, the atoms of carbon will be 89, of hydrogen 72.

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But if a second analysis gives 53·34 per cent carbon and 7·02 hydrogen, a deviation of only ·2, we shall get $53{\cdot}34 \div 6 = 8{\cdot}9$ and $7{\cdot}02 \div 1 = 7{\cdot}02$, or 89 and 70 as the equivalents. So that this slight deviation leads to a difference of two atoms of hydrogen, solely because its atomic weight is six times less than that of carbon.

286. The decision of many physiological questions requires a comparison of the quantities of carbon, hydrogen, nitrogen, and oxygen, which are introduced in the food, with those which are given off in the urine and fæces. Since large quantities are here concerned, while elementary analysis is only occupied with small ones—usually only 3 or 4 grains—two difficulties are present. The food daily taken by a man or animal is a mixture of organic substances of the most different kinds. It is therefore uncertain whether the substance chosen for analysis offers the same mixture as that of the food usually consumed. And since the calculation embraces three or four thousand times the quantity just mentioned, any error in the elementary analysis of the two or three grains is greatly multiplied. This disadvantage may be obviated by accidental compensations. But it is possible that the error may be considerably increased by unlucky coincidences. And questions of any delicacy can scarcely be decided in this way. Thus we can never determine from such researches how much less nitrogen is discharged in the urine and fæces, than is introduced in the food; or how much passes out by the pulmonic and cutaneous evaporation, and by the process of desquamation.

287. Since the oxygen of bodies subjected to elementary analysis is only obtained negatively, as a deficiency (§ 275), it forms, as it were, the *resumé* of all the sources of error of the other constituents. Thus, if the carbon of a non-azotized compound which has no ash is just so much too little, as the hydrogen is too much, the quantity of oxygen may chance to be correct. But if all the errors are on the same side, if all are positive, or all negative, the quantity of oxygen will form a sum total of the errors.

288. No organized substance contains sufficient oxygen to convert all the carbon present into carbonic acid, and all the hydrogen into water. Hence, in order to a complete combustion, new oxygen must be added from without. Both on physical and physiological grounds, it has often been attempted to determine the equivalent value of this superadded quantity. But there are sources of error which render this attempt always more or less insecure.

289. The albuminous substances, so important to the living being, and probably many other organic compounds, contain sulphur and phosphorus, together with carbon, hydrogen, nitrogen, and oxygen. The first two of these can scarcely be followed with such precision as to permit an accurate statement of their amounts. With oxide of copper at a red

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heat, sulphurous acid is set free: and as it is taken up by the solution of potash, the apparent amount of carbon is increased. And hence bodies which contain much sulphur may lead to very considerable errors. We shall hereafter see that there is a similar danger of error from many constituents of the ash.

290. Up to the present time chemistry has regarded the majority of the fixed combinations as merely supplementary to the volatile: and it was only in exceptional instances that any attempt was made to unite them in one general view. It is, however, more than probable that most, if not all, organic tissues proceed from complex and intimate fusion of all the various kinds of matter which may be detected in them. So that organic substances the most diverse may result from the union of the same volatile matters with different ashy constituents.

291. The ash furnished by a red heat is often a mixture which differs greatly from the sum of the inorganic substances of the corresponding fresh animal or vegetable part. The changes which accompany the formation of the ash may often be accurately followed. But many points worthy of consideration must be at present deferred.

292. The bones, the teeth, and the crystalline globules deposited in the alkaline urine of mammalia, contain certain quantities of carbonic acid. If a given quantity of their dried powder be mixed with a known weight of nitric acid, so that the carbonic acid is expelled by the latter, the quantity of the gas so driven off may be calculated from the total loss of weight, allowing for the circumstances of aqueous evaporation. In comparing this with the carbonic acid found in the ash of these parts, three cases may occur. As an instance of the first, we may adduce the fact, that a pulverized human femur yielded 4·57 per cent of carbonic acid, and the ash of the same bone 4·53. Here combustion causes no difference. But the teeth similarly heated give 3·26, and 2·17; so that part of the carbonic acid was lost at a red heat. Finally, the solid part of the urine of the horse gave 36·92 per cent of carbonic acid in the fresh state: while the loss of the weight in the ash amounted to 37·78 per cent. It might have been conceived that the loss in the latter case was possibly due to a salt of some organic acid having been changed into a carbonate. But a narrower examination revealed the true cause of the increase. Since the sulphates then present were changed into metallic sulphurets at the red heat, the addition of nitric acid set free sulphuretted hydrogen, which escaped together with the carbonic acid. And thus we see, that the carbonic acid, which we find in the ash, affords a very inaccurate measure of that originally present in the fresh state.

293. The red heat may produce other important changes in the various constituents; so that an analysis of the ash yields compounds which were not originally present. Besides this, many substances are volatilized, so that too small a quantity of ash is obtained.

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294. The sulphur contained in fresh organic tissues is converted by burning into sulphuric acid. This next seeks to change the carbonates present into sulphates: and if a red heat be long applied to bodies rich in nitrogen and carbon, sulphurets of the metals are formed, and sulphurous acid is set free. If urine contains acid phosphate of soda, a part of the phosphoric acid is given off at a red heat [10]): and phosphate of soda can set free both sulphuric and hydrochloric acids.

295. If the ash were simply mixed with the organic constituents, it might be expected that proper solvents would withdraw the whole of it from the fresh or charred mass. In the bones this is actually the case. And hence, according to Rose's expression, they belong to the class of teleoxygenous organic bodies. For water and acids remove from the fresh tissue all those salts which remain after incineration. The teeth, the otolithes (Tab. I., Fig. IV.), and the crystalline globules (Tab. I., Fig. XXI.), probably possess similar characters. The burnt mass of other organic substances is meroxygenous, *i.e.*, it yields to proper solvents a smaller amount of inorganic matters, than does the ash. For instance, in Rose's experiments, the solid residuum of ox's blood yielded 33 per cent less, and white of egg 51 per cent less; while albumen exhibited a difference of only 2·3 per cent, and the solid residue of the urine only ·6 per cent. But no organic substance hitherto examined is anoxygenous, *i.e.*, its charred mass is never capable of retaining all its mineral constituents under the influence of water and hydrochloric acid.

296. The properties of these meroxygenous bodies confirm our previous (§ 263) conjecture, that many coustituents of the ash are in some peculiar state of chemical combination with the volatile elements. The nomenclature of Rose, which has just been referred to, is based upon his notion, that these constituents are contained in the fresh substance in a metallic and not oxidized state. A very simple counter-experiment suffices to show that this peculiarity does not pertain to the charred mass itself. If sugar, which itself contains no fixed matters (§ 262), be mixed with the ordinary ashy constituents, and the whole mass charred, these may be completely withdrawn from it by means of the ordinary solvents.

297. The quantitative analysis of the several constituents of mixtures like the blood, the urine, and the solids of our organism, is met by such serious obstacles, that the most careful researches can at best but lead to approximative values, which can only be made use of within certain limits. The quantity of coagulative fibrine varies greatly with collateral circumstances. Similarly, it depends on the other combinations present whether all, or only part, of the albumen is precipitated by coagulation. The same cause breaks down many bodies, such as urea. It hinders the recognition of particular elements, such as iron, which is easily found in the ash in a much larger quantity. Finally, the chemical process adopted may form new compounds, or metamorphose those originally

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present. Mere exposure to the atmosphere for some time often changes susceptible fatty matters, which take up oxygen greedily. An examination of the bile has yielded different combinations to almost every modern chemist, since the ease with which this mixture is decomposed usually develops new products at each step of the experiment. If we add sulphuric acid to a sufficiently strong solution of urea, a part of this substance is decomposed into carbonic acid and ammonia. And we shall hereafter see, that it is at present doubtful whether many of the excretory substances obtained from the urine, or other constituents of the body, are really originally present. Spontaneous decomposition leads to similar evils. Thus, instead of kreatin, we get kreatinin; instead of the hippuric, the benzoic acid; instead of urea, carbonate of ammonia. In short, an analysis resembles every other scientific observation, in being valuable only when the process is stated by which the results were obtained. When the observer is either silent about the means which he has employed, or communicates them mysteriously or insufficiently, the analysis itself is almost useless.

298. Ordinary chemical decomposition consists in a mutual exchange of equivalents, dictated by the degrees of affinity. Since the atomic weight of carbonic acid is 22, and that of potash 48, 100 parts of simple carbonate of potash contain 31·43 of carbonic acid. Now if the equivalent of sulphuric acid be 40, 57·14 parts by weight are required to expel the whole of the carbonic acid, and produce simple sulphate of potash; and if less be used, the change is only partially effected; while if more be added, a corresponding superfluous quantity of sulphuric acid remains in the free state. The amount of result here corresponds to that of the operation.

299. There are many facts which apparently lead to different conclusions. Sometimes it is only necessary that one substance should be present in very small quantity, to give rise to very energetic chemical changes in another one. Slight traces of diastase suffice to convert considerable quantities of paste into dextrine and grape-sugar. A little ferment is sufficient to make sugar undergo fermentation, and yield carbonic acid. The mere presence of a metal such as platinum, which appears to remain unaltered, decomposes the binoxide of hydrogen into oxygen and water. Berzelius ascribed these phenomena to a catalytic force. But just the reverse of this may occur: small quantities of one substance may prevent the decomposition of other masses. A drop or two of sulphuric acid enable many drachms of prussic acid to retain their power for years. These influences, which are exerted by particular substances, in spite of their extremely small quantity, have been included under the name of contactive operations.

300. In all of these cases two secondary causes usually obtain. The compound which yields to the influence of contact has an independent facility of decomposition. Its molecules are, as it were, loosely united.

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The change, however, does not appear at once in the whole mass; but occurs gradually. These facts support the opinion lately defended by Liebig, that we have here an action which passes from molecule to molecule. Such substances as diastase and ferment are supposed to be undergoing a metamorphosis, which in its turn determines a change in the chemical relations of the surrounding atoms of the body that is exposed to this contactive influence. The decomposed molecules operate upon their neighbours in like manner. And thus, the longer the process continues, the more extensive are the results. But since the sum of the atoms acting by contact is continually enlarging, *cæteris paribus*, the quantity of decomposition in an unit of time is similarly increased.

The influence of sulphuric upon hydrocyanic acid may be similarly explained. We may imagine, that traces of organic substances, mixed with the hydrocyanic acid, gradually decompose it by a contactive process; and that sulphuric acid hinders the process by charring these matters.

301. Contactive phenomena of this kind are made use of in certain functions of the living body. We shall hereafter see that many parts of the digestive process, and even the fertilizing influence which the semen exerts upon the ovum, are based upon such actions.

302. The metamorphosis which occurs in the living animal is chiefly influenced by three organic groups: the hydrates of carbon, the fats, and the albuminous substances.

303. One atom of water consists of one atom of oxygen and one atom of hydrogen. Now when an organic compound contains the same number of equivalents of oxygen and hydrogen, together with a certain atomic quantity of carbon, but without nitrogen or ash, we may imagine that the atoms of hydrogen and oxygen are present with the same mutual relations as in water, and that the carbon forms an addition to this supposed hydrate. The name hydrate of carbon has reference to this theoretical view. But it is obvious, that we are not justified in assuming these bodies to be true compounds of carbon with water.

304. We may conveniently arrange the most important substances belonging to this class as follows:

Substances.	Quantities per Cent.			Equivalent Proportions.
	C	H	O	
Starch	43·65	6·67	49·68	$C_{12} H_{10} O_{10} = A_1$
Gum	42·10	6·37	51·53	$C_{12} H_{11} O_{11} = A_1 + H_1 O_1$
Anhydrous cane-sugar .	44·38	6·41	49·21	$C_{12} H_{10} O_{10} = A_1$
Crystallized sugar of milk	39·58	6·72	53·70	$C_{12} H_{12} O_{12} = A_1 + H_2 O_2$
Anhydrous lactic acid .	44·30	6·12	49·58	$C_6 H_5 O_5 = \frac{1}{2} A_1$
Acetic acid . .	39·45	6·67	53·88	$C_4 H_4 O_4 = \frac{1}{3}(A_1 + H_2 O_2) = C_4 H_3 O_3 + H_1 O_1$

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We see from this that gum contains one atom more water, and crystallized sugar of milk two atoms more water, than starch and anhydrous sugar; while the two latter exhibit the same equivalent composition. And on comparing the parts per cent we see at a glance what important differences are exhibited by our ultimate analyses even in the case of the more simple organic compounds (§ 279).

305. The fatty bodies in a state of purity also belong to the non-azotized organic substances. But fat and the fatty acids are distinguished by having a very high percentage of carbon, and a very low one of hydrogen and oxygen. The small atomic weight of hydrogen, nevertheless, produces a close approximation in their equivalent numbers. For instance:

Substances.	Percentage Composition.			Equivalent Proportions.
	C	H	O	
Human fat	77·92	11·42	10·66	$C_{10} H_9 O_1$
Elain of the human brain	78·41	11·90	9·69	$C_{10} H_9 O_1$
Olive oil	76·15	13·36	10·49	$C_{10} H_{11} O_1$
Hydrous elaic acid	76·60	12·06	11·34	$C_{36} H_{34} O_4 = C_{34} H_{33} O_3 + H_1 O_1$
Hydrous margaric acid	75·56	12·59	11·85	$C_{34} H_{34} O_4 = C_{34} H_{33} O_3 + H_1 O_1$
Hydrous stearic acid	76·69	12·78	10·53	$C_{68} H_{68} O_7 = C_{68} H_{66} O_5 + H_2 O_2$
Cholesterin (of bile)	83·74	12·00	4·26	$C_{30} H_{27} O_1$
Glycerin	39·52	8·94	51·54	$C_6 H_7 O_5 = C_6 H_6 O_4 + H_1 O_1$

306. The fats saponify under the influence of alkalies. The fatty acids thus set free unite with them to form salts. Thus, for instance, ordinary hard soap contains from 50 to 69 per cent of elaic acid (with which is mixed a small quantity of sebacic acid), 4½ to 10 per cent of soda, and 21 to 45 per cent of water. It is thus a soda-soap. The green soft soap is a potash compound, and consists of 44 per cent of fatty acids, 9½ potash, and 46½ water. In the same way, lead-plaster is a compound of oxide of lead with the fatty acids of the olive or other oils from which it is prepared. A considerable quantity of glycerin is also set free during the process, and is dissolved in the water which is present.

307. It is supposed by chemists that the natural fats are similar soaps with organic bases. It was formerly thought that glycerin acted the part of a base. But as a more careful examination into the circumstances which attend decomposition was found to militate against this opinion, a hypothetical radical was assumed, and called lippyl ($C_3 H_2$). It was presumed that the fats were salts formed by the fatty acids with oxide of lippyl. The fluid elain was thus an elaate of the oxide of lippyl, while the solid stearin and margarin were its stearate and margarate respectively. And when the fatty acid is separated by other acids, glycerin is produced from the oxide of lippyl, with the aid of some atoms of water [$C_6 H_7 O_5 = 2 (C_3 H_2 O_1) + 3 (H_1 O_1)$].

308. If the fatty matter of the bile be heated for some time with con-

centrated solutions of the alkalis, it remains undecomposed. Hence cholesterin does not possess the capacity of forming soaps with inorganic bases.

309. We see by the table in § 305 that the number of equivalents of carbon and hydrogen in the fatty acids greatly exceeds that of oxygen and hydrogen. On this account there was formerly a strong inclination to regard them as hydro-carbons, mixed with oxygen. Theoretical considerations led to the attempt to group the formulæ of many organic compounds in such a way as that certain constant equivalents of oxygen should be contrasted with multiple equivalents of hydrocarbon. Thus making such an attempt with O_4, we may arrange in this way many of the volatile fatty acids, and even the not very volatile margaric acid, as well as several other organic substances.

Substances.	Equivalent Proportions.
Formic acid . . .	$C_2\ H_1\ O_3 + H_1\ O_1 = (C\,H)_2\ O_4$
Acetic acid . . .	$C_4\ H_3\ O_3 + H_1\ O_1 = (C\,H)_4\ O_4$
Butyric acid . . .	$C_8\ H_7\ O_3 + H_1\ O_1 = (C\,H)_8\ O_4$
Valerianic acid . . .	$C_{10}\ H_9\ O_3 + H_1\ O_1 = (C\,H)_0\ O_4$
Capreic acid . . .	$C_{12}\ H_{11}\ O_3 + H_1\ O_1 = (C\,H)_{12}\ O_4$
Caprylic acid . . .	$C_{16}\ H_{15}\ O_3 + H_1\ O_1 = (C\,H)_{16}\ O_4$
Caprinic acid . . .	$C_{20}\ H_{19}\ O_3 + H_1\ O_1 = (C\,H)_{20}\ O_4$
Margaric acid . . .	$C_{34}\ H_{33}\ O_3 + H_1\ O_1 = (C\,H)_{34}\ O_4$

We shall find many of these substances occur very frequently in physiological researches. They may either be produced during life, or as a result of putrefaction, or under the influence of artificial chemical decompositions.

310. An examination into the phenomena of nutrition will teach us, that even microscopic observation indicates a certain relation between the most highly coloured matters of the animal body, and the fatty substances. It is true that the elementary analyses hitherto undertaken have shown a considerable amount of nitrogen in the hæmatin or colouring matter of the blood, in the melanin which forms the basis of the black pigment, and in the cholepyrrhin or colouring matter of the bile. But none of these have been isolated in a state of sufficient purity to prevent the suspicion of admixture with other and foreign azotized combinations. It seems possible that binary compounds of fatty and other substances here occur. Be that as it may, the equivalents deduced for these impure mixtures seem to indicate, that the most important coloured tissues of the animal body are distinguished by containing a considerable quantity of carbon. Although the superadded nitrogen, and the iron calculated for some analyses, considerably lower the percentage of the other constituents, we nevertheless find 65·35 per cent of carbon in the hæmatin, and 57·94 to 72·95 in the melanin.

311. The group of albuminous substances, or protein compounds, as they are now usually termed, forms the centre of those organic substances

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on which the construction of the most highly azotized tissues of our body immediately depends. Albumen, fibrin, and casein can be collected in a state of tolerable purity; and have hence been, to some extent, accurately investigated. But it is more than probable that even here also we are only concerned with varying mixtures of different substances,—that many of their more obvious properties depend, not so much on the original nature of the organic compound, as on that of the matters present with it. There are other bodies of this kind which lead to yet more variable results, since it seems impossible to exhibit them in a sufficiently constant and uniform state. Such are the oxides of protein, the globulin which is obtained from the blood, the albumen contained in the yolk or vitellin, legumin, and vegetable gluten.

312. Mulder formerly supposed, that a peculiar azotized compound — protein — formed the basis of albumen, fibrin, and casein. The equivalents of sulphur and phosphorus united with it were believed to constitute the distinction between these three bodies. But later researches have shown, that the phosphorus cannot be reduced to the atomic numbers which he assigned it; and that it is equally impossible to produce a protein which is devoid of sulphur. Hence the equivalent numbers which have been assigned to the elements of protein or other albuminous bodies, without respect to their sulphur, do not represent the constituents which remain after the subtraction of the salts of their ash. If it is also recollected, that many albuminous bodies obstinately retain mixtures of their fatty and fixed constituents, and that, in all probability, many of these are immediately united with the organic substances, it will be evident, that the most exact ultimate analysis can only furnish a very incomplete glimpse of the composition of these bodies. If we retain the equivalents hitherto assumed, we get as follows:—

Substances.	Percentage Composition.				Hypothetical Equivalents.
	C	H	N	O	
Albumen . .	53·48	7·17	15·73	23·62	$C_{48}H_{39}N_{12}O_{16}$
Fibrin . .	52·68	6·99	16·60	23·73	$C_{48}H_{38}N_{12}O_{16}$
Casein . .	54·21	7·15	15·80	22·84	$C_{48}H_{38}N_{12}O_{15}$

313. These substances may appear in the coagulated or non-coagulated form. In the latter case, they are dissolved in an alkaline fluid, or in solutions of certain salts. In the former case, they are precipitated in the solid form. At present the more delicate changes upon which these differences are based are not accurately known. The coagulation of the blood depends on the separation of its fibrin, and that of acidifying milk on the deposit of its casein.

314. It is usual to speak of an albumen of the egg, and one of the

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blood-serum; or of a fibrin of the blood, and of the muscles. It is more than probable that the composition of these synonymous substances is not completely identical. At any rate there are facts which quite suffice to indicate that albumen, fibrin, and casein, do not constitute three distinct compounds, but that they frequently merge into each other. One of the main advantages made use of by nature in the construction and maintenance of the tissues seems to consist in the numberless changes of which the compounds included in this albuminous group are capable. In this way a slight difference in the relative quantity of their organic constituents induces a considerable alteration of their physical properties; and from a determinate amount of decomposition, foreign substances are easily produced. The chemical influences to which albuminous matters are subjected in artificial experiments are probably far too energetic to enable us to recognize, with even tolerable accuracy, those finer processes of metamorphosis pursued by Nature herself in the living body.

315. If the different horny tissues, together with the areolar tissue, the tendons, and the membranes composed from the union of the fibrous tissues,—such as the corium, or the membrane of the isinglass,—and the cartilage of bone be boiled in water, a part of their substance is converted into gelatin, which remains dissolved at this temperature, but congeals to a jelly on cooling. The cartilages of the adult furnish another kind of glue, called chondrin, and the elastic tissue a third variety, which is distinguished from this latter through its not being precipitated by sulphate of iron.

316. An attempt has been made to divide the tissues into two classes, the albuminous and gelatinous.* The first are said to be distinguished by their being precipitated from their solutions in acetic acid by the ferrocyanide of potassium, and from their smallest traces being detected by the nitrate of mercury. The latter are stated not to exhibit this reaction with the ferrocyanide of potassium. But we may easily convince ourselves that the acetic solution of areolar tissue, of tendon, and of other gelatinous bodies, is precipitated by the addition of this salt of iron. It is hence evident, that the fact of containing an albuminous substance is not incompatible with the capability of being converted into gelatin at a higher temperature.

317. Since gelatin is the result of a change effected under the influence of water and a high temperature, we might expect that its composition would differ from that of the substances out of which it is produced. Its ultimate analysis is subject to the difficulties already mentioned; viz., that it is a mere mixture of substances which we examine, and that slight differences in the collateral circumstances may

* The terms here used are those familiar to the English student of physiology; but the richer and more accurate German adjectives imply that the two classes *contain* albumen, and *yield* gelatin, respectively.—*Editor.*

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cause important alterations in its characters. But the results hitherto obtained may at least serve to show that the quantities per cent are little, though visibly, changed. For instance :—

Substances.	Percentage Composition.				Hypothetical Equivalents.
	C	H	N	O	
Human skin from the sole of the foot	50·20	6·78	17·23	25·79	$C_{48} H_{39} N_{14} O_{18}$
Human hair	50·22	6·39	17·23	26·16	$C_{48} H_{39} N_{14} O_{18}$
Tendon	50·14	7·17	18·32	24·37	$C_{48} H_{41} N_{15} O_{17}$
Air-bladder of the sturgeon . .	49·42	6·90	18·79	24·89	$C_{48} H_{40} N_{15} O_{18}$
Glutin from the same . .	49·37	6·56	18·37	25·70	$C_{48} H_{33} N_{15} O_{19}$
Glue from cartilage . . .	49·47	6·66	14·49	29·38	$C_{40} H_{32} N_{10} O_{18}$

318. The composition of the albuminous substances contained in vegetables closely corresponds with that of the albumen of animals : so much so, that it has been alleged, although probably with incorrectness, that they are identical in both the kingdoms of nature. The ultimate analysis of chitin, a substance which occurs in the horny wing-cases of insects, and in many other parts of several invertebrata, led Schmidt, Koelliker, Loewig, and Lehmann to the opinion, that it consists of a hydrate of carbon, similar to vegetable fibre, and united with a highly azotized substance.

319. Many of the alkaloids and their congeners may be obtained from the fresh animal tissues, in health or disease, or as products of their decomposition. To this group of organic substances belong kreatin ($C_8 H_9 N_3 O_4$), and kreatinin ($C_8 H_7 N_3 O_2$), which may be obtained from muscle, soup, and urine; the glucin ($C_4 H_5 N_2 O_4$), which is produced by the decomposition of glue by means of strong acids; leucin ($C_{12} H_{13} N_2 O_4$), which, according to Mulder, corresponds with oxide of casein, and which may be obtained either artificially from casein, flesh, or gluten, and also by the putrefaction of casein or gum; and tyrosin ($C_{16} H_9 N_2 O_5$), which is precipitated from the alkaline solution of albuminous substances by acetic acid. So likewise the urine, and the fluid of the allantois, which is related to it, furnish many compounds that may be regarded as alkaloids containing oxygen. Thus, for instance, urea ($C_2 H_4 N_2 O_2$), allantoin ($C_4 H_3 N_2 O_3$)—which has been found in the fluid contents of the allantois of many ruminants, and in the urine of young calves:—Guanin ($C_{10} H_5 N_5 O_2$), which has been observed in guano and in the excrement of spiders, and xanthin ($C_5 H_2 N_2 O_2$), and cystin, which appear in many urinary calculi.

320. Some of these compounds are distinguished by being rich in sulphur. The taurin obtained from bile ($C_4 H_7 N S_2 O_6$) contains, according to Redtenbacher, 25·6 per cent, and cystin ($C_6 H_6 N S_2 O_4$) 26·7 per cent of sulphur.

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321. We shall see that the urine is the means of excreting a great part of the nitrogen required to leave our body. From it we obtain many substances,—urea, uric acid, and hippuric acid—which form a series with a diminishing quantity of nitrogen. The hippuric acid finally yields the non-azotized benzoic acid, as the product of its spontaneous decomposition. The results of an ultimate analysis of these substances are as follows:—

Substances.	Percentage Composition.				Equivalent Proportions.
	C	H	N	O	
Urea	19·75	6·71	46·73	26·81	$C_2\ H_4\ N_2\ O_2$
Uric acid	35·33	2·38	34·6	27·69	$C_5\ H_2\ N_2\ O_3$
Hippuric acid . .	59·91	4·96	7·82	27·31	$C_{18}\ H_9\ N\ O_6$
Benzoic acid . .	68·30	4·86	..	26·84	$C_7\ H_3\ O_2$

322. Urea is the most azotized substance hitherto met with. It may be artificially obtained from cyanate of ammonia, by way of interchange ($C_2NO+NH_3+HO=C_2H_4N_2O_2$). A glance at the remainder of the above table shows us, that the amount of carbon continually increases while that of the nitrogen decreases.

323. The spontaneous decomposition of the organic substances is favoured by their looser mutual connection, as well as by heat, oxygen, water, or the presence of other substances already undergoing metamorphosis. Fermentation and putrefaction, although ascribed exclusively to the constituents of plants and animals, do not essentially form processes to which there is no parallel in the inorganic world. The union of the constituents of organic bodies, their easier transition into other substances, and their inclination to form products of combustion, only furnish a more favourable nidus for incidents, the operation of which is not altogether unknown even in inorganic matter.

324. When starch ($C_{12}\ H_{10}\ O_{10}$), or the paste produced by boiling it in water, undergoes fermentation, dextrin (§ 173) is first formed, and subsequently grape sugar ($C_{12}\ H_{10}\ O_{10}$). According to existing chemical ideas, we have here a simple interchange of atoms. Sugar of milk or lactin ($C_{12}\ H_{12}\ O_{12}=2\ (C_6\ H_5\ O_5)+H_2\ O_2$) is often transformed into lactic acid ($C_6\ H_5\ O_5$). Here the only change is the loss of the atoms of water. The first of these is named the saccharine, and the second the lactic, fermentation.

325. The vinous and acetous fermentations consist in the appearance of these substances respectively, as secondary products of metamorphosis. Cane and milk sugar are converted into grape sugar, before giving rise to the formation of alcohol. The production of alcohol is capable of setting free carbonic acid. But in order to this, the addition of oxygen is not

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absolutely necessary. Some atoms of water are all that is required. Thus one atom of crystallized sugar of milk ($C_{12}H_{12}O_{12}$), or one atom of anhydrous cane-sugar ($C_{12}H_{10}O_{10}$) + 2 atoms of water (H_2O_2) = 4 atoms of alcohol ($C_2H_3O_1$) + 4 atoms of carbonic acid (4 CO_2). But when alcohol is converted into vinegar, an increment of oxygen is required; for 2 atoms alcohol ($C_4H_6O_2$) + 4 atoms of oxygen = 1 atom acetic acid ($C_4H_4O_4$) + 2 atoms of water (H_2O_2).

326. When fats become rancid, fatty acids are produced. The putrefaction of albuminous bodies, and even the fermentation of hydrates of carbon which they induce, give rise to the evolution of volatile fatty acids. The putrefaction of the coagulated fibrine of the blood furnishes butyric acid, with carbonic acid, sulphuretted hydrogen, ammonia, leucin, and tyrosin. Under similar circumstances, casein, which is devoid of fat, first forms carbonate of ammonia and sulphuret of ammonium; and at a later period, ammonia, valerianic and butyric acids, leucin, a substance having a fæcal odour, and an acid which undergoes decomposition into ammonia, tyrosin, and another compound. If cane-sugar be allowed to ferment under the influence of casein, carbonic acid and hydrogen are set free, while butyric acid accompanies their formation. Sugar of milk also exhibits the phenomena of butyric fermentation. Under the influence of putrefying albuminous substances, the lactate of lime is converted into the butyrate of the same earth.

327. Putrefying urea is converted into carbonate of ammonia. One atom of urea ($C_2H_4N_2O_2$) + 2 atoms water (H_2O_2), give 2 atoms of carbonate of ammonia [$2(NH_3 + CO_2)$]. This circumstance contributes to the alkalinity which the originally acid human urine assumes in the course of spontaneous decomposition. It is also conceivable that the access of oxygen and water transforms uric acid into urea and carbonic acid. For one atom of uric acid ($C_5H_2N_2O_3$) + 3 atoms of oxygen (O_3) + 2 atoms of water (H_2O_2) = 1 atom of urea ($C_2H_4N_2O_2$) + 3 atoms of carbonic acid (3 CO_2). And finally, we have already seen (§ 321), that the putrefaction of hippuric acid ($C_{18}H_9NO_6$) evolves the non-azotized benzoic acid ($C_7H_3O_2$).

328. From what has just been mentioned it is evident, that hydrogen, water, carbonic acid, and ammonia, are frequently set free in the processes of fermentation and putrefaction; while, *vice versâ*, these processes often demand the addition of oxygen, or of atoms of water. The mode of decomposition, and the products to which it gives rise, vary with the attendant circumstances, and with the degree of warmth which is present to facilitate the process. If water is at the same time decomposed, or hydrogen furnished from other sources, a part of the carbon may be converted into carburetted hydrogen. The incomplete access of oxygen may furnish carbonic oxide. Sulphur and phosphorus are often metamorphosed into sulphuretted and phosphuretted hydrogen.

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329. By chemical processes, and especially by means of oxidizing substances, we can artificially produce not only the putrefactive gases, but also many of the organic compounds which accompany them. The spontaneous decomposition seen in many organic substances, depends upon a series of interchanges, which are facilitated, and now and then hastened, by collateral causes; but it does not depend upon special phenomena, which no other circumstances can reproduce. Since the results are frequently determined by the access of oxygen, fermentation and putrefaction have been represented as a kind of combustion. But from what has been already stated it is evident, that this view is to a certain extent one-sided. Many of the phenomena of interchange which accompany these two processes only require atoms of water, and many do not even demand this to go through at least a certain part of their course.

330. This statement may be immediately applied to the living body. The oxygen taken up by the blood certainly forms the basis of many of the metamorphoses of substance. The evolution of carbonic acid, and the production of water, to which the inspired oxygen contributes, support the idea, that there is a process of combustion, and an energetic elementary analysis, continually going on in our body. But this change does not always proceed directly and completely to its uttermost; since the effete compounds are not entirely converted into carbonic acid, water, nitrogen, or ammonia, but also into other organic bodies, such as urea, uric acid, hippuric acid, colouring matters, mucus, and other excretory products. Hence we have a limited elementary analysis, and not a putrefaction which is carried out to its ultimate results. It is more than probable that many phenomena of interchange occur quite independently of any assistance from the inspired oxygen, just as many stages of fermentation are possible without the access of atmospheric air.

331. The looser atomic affinity which is exhibited by the most important compounds in the human body, the presence of oxygen, and of water (with which it is everywhere saturated), favour that spontaneous decomposition which, when more or less unimpeded, constitutes putrefaction. The arrangement of the living organism, the continual movement of the blood, the limited access of oxygen, the degree of warmth which in a great measure depends on it, the exclusion of many tissues from the access of the atmosphere, the periodical ejection of useless organic compounds which are useful in claiming the oxygen introduced, and finally, the suitable propinquity of tissues which act upon each other, — all these are circumstances which permit the body so beautifully to fulfil its final causes, not merely in spite of the great mutability of its materials, but rather because of it (§ 8). It thus possesses a capacity of continual fluctuation, which only fails under certain morbid conditions; and even then, not unfrequently furnishes products which in a great degree correspond with those of an unimpeded putrefaction.

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332. The combinations which are produced by spontaneous decomposition, and which can be artificially obtained, not unfrequently recur in the living body in a certain series. The starch taken as food is capable of changing into sugar, and sugar of milk into lactic acid. Volatile fatty acids are frequently produced from fats or hydrates of carbon. Organic salts are converted into carbonates, prior to their removal by the urine. According to Liebig, the watery extract of muscle contains no trace of urea. But the kreatin which it yields is decomposed into sarcosin and urea or carbonate of ammonia (§ 327) by the action of caustic baryta at a high temperature. It is not improbable that part of the uric acid of the living body undergoes a transformation into urea and carbonic acid (§ 327). And a consideration of the changes which are undergone by different substances from their entrance into the intestinal canal to their exit in the urine, will explain many similar phenomena. The total change of matter depends upon a mutual metamorphosis, which differs both in its quality and quantity from putrefaction and simple combustion. For the several constituents of our ever militant organism have an exact mutual action, which permits none but certain determinate decompositions, so long as health endures.

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CHAPTER VI.

DIGESTION.

333. The great object of food is, to replace those compounds which have been rendered useless or have been expelled from the body by other functions, and thus to maintain unaltered the bulk of the organized being. Under favourable circumstances it also furnishes a certain surplus, which is applicable to the increase of the existing parts, or to the growth of the entire organism.

334. In order that the substances thus introduced should be capable of fulfilling this purpose, they must be transformed into definite organic combinations. Since these are composed of the simple substances of inorganic nature, it might seem in itself not impossible that the latter should fulfil the purpose of food. But we are here met by a peculiar law, which not only holds good for the nutrition of the individual, but also, in a similar way, for the maintenance of the species. In the phenomena of reproduction we shall see that, so far as we know, there is no new organized being of the existing world which is produced immediately from inorganic matter. Each springs from certain organic combinations, which were in their turn derived from a parent mass of the same kind. And in the same way, the individual can only be sustained by an organic, and not by an inorganic, food.

335. But we are not hence to suppose these inorganic substances useless. On the contrary, the gases and minerals introduced in the water, the decoctions, and fermented liquors which we drink, together with the ashy constituents contained in the more solid food, and the salts,—such as common salt,—which we use to season it, are frequently made subservient to the metamorphosis of organic structures. And those parts which contain a large quantity of ash, or a considerable proportion of soda or phosphatic compounds, require a regular supply of these substances. The carbonic acid of the water we drink can hold in solution the simple carbonate of lime which is so necessary to the organism, while the salt we eat may introduce the requisite soda.

336. Since food may be derived from the vegetable or animal kingdom, its primary division is into vegetable or animal. A combination of the two constitutes a mixed diet. And an examination into their elementary constituents leads to a distinction which is much more important than this superficial one. The hydrates of carbon, such as starch and the

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different kinds of sugar, together with the pure fatty and oily substances, form non-azotized aliments: while the albuminous substances are azotized. A mixed diet will contain ternary and quaternary organic compounds (§ 269). Most of the substances which Nature offers as food belong to this mixed class. The potato chiefly contains starch, but the granules (Tab. I. Fig. XVII. *a*) of this material constitute only the contents of its cells: the remaining part of its substance contains nitrogen, though only in sparing quantity. The adipose tissue exhibits a similar condition. The oily content of the fat-cells (Tab. II. Fig. XXVII.) consists only of carbon, hydrogen, and oxygen; while their walls, as well as the foreign tissues which occupy their interstices, are composed of albuminous materials. And although most of the animal tissues belong to the class of azotized substances, still flesh must be regarded as a mixed food, since fat cells are interposed between the muscular fascicles.

337. The sensation of hunger, which is especially felt in the stomach, and that of thirst, which is chiefly situated in the throat, reveal to us the necessity of solid and fluid aliment, of food and drink. But daily experience teaches us, that these two kinds of sustenance, which chiefly differ from each other by the degree of their density, cannot be absolutely distinguished. A juicy fruit assuages thirst, and a strong semisolid jelly, or a cup of chocolate, allays hunger. Chemical examination explains why their effects thus merge into each other. For the ordinary drinks contain more or less solid matter. And even those kinds of food which appear to be perfectly dry give off considerable quantities of volatile combinations on exposure to high temperatures.

338. The water of a running spring at Bern has a specific gravity of 1·0005 to 1·0008 at 46·4 to 50°; and evolves oxygen, nitrogen, and carbonic acid at the boiling point. The total quantity of these gases amounts to from 4·47 to 8·03 per cent—on an average to 6·8 per cent—of the volume of liquid from which they are expelled. The water itself contains silicic acid, chloride of sodium, chloride of calcium, chloride of magnesium, nitrate and sulphate of soda and potash, carbonate, nitrate, and sulphate of lime, carbonate and sulphate of magnesia, and iron. These substances altogether weigh from 1-44th to 1-14th, or on an average 1-20th, per cent of the water. Sixty-one cubic inches contain from 3·07 to 6·1 grains of carbonate of lime: the average quantity being 4·85.

339. A good meat broth leaves about $1\frac{1}{2}$ per cent of solid matters: lemonade $3\frac{1}{2}$, Rhine wine 2 to $5\frac{1}{2}$, and strong beer $4\frac{1}{2}$ to $7\frac{1}{3}$ per cent. Juicy cucumbers only yield about 3, and fresh onions 6 per cent.

Raw potatoes and fresh beef each lose about $\frac{3}{4}$ths of their weight when thoroughly dried; and bread somewhat less than half its weight. Peas, beans, and lentils give off 14 to 16 per cent. Unripe cherries, plums, and apricots, generally contain rather more water than ripe fruit of the same kinds.

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Unless some part of it is converted into volatile fatty acid, it is evident that the adipose tissue can only lose so much in drying as is given off by the foreign tissues which it contains. Thus hog's lard only loses 2·4, and mutton suet 3·8, per cent. Crystallized cane-sugar only loses the water condensed between its minute particles: thus it yields scarcely ·6 per cent.

340. The fact, that a solid and apparently dry aliment introduces a certain quantity of water into the body, must be constantly borne in mind in all researches having reference to this part of the metamorphosis of matter. For instance, a diabetic patient may pass more water in his urine than he has taken in the form of drink. But if we add to this the quantity of water contained in his food, we shall generally find that it makes up for the difference.

341. The intoxicating effect of fermented drinks mainly depends on their alcoholic contents. The different varieties of beer usually include from 1·5 to 8·33 per cent by volume of absolute alcohol. Rhine wines give 9·8 to 12·7 per cent, the white French wines 12·3 to 14·2, the red 12·4 to 23·, the sacks, or sweet wines, 9·9 to 25·9, and genuine champagne 11·8 to 13·3. But it is obvious, that the other constituents which are present with the alcohol exercise an important influence on the effect of the drink. The smell of wine depends on the œnanthic ether contained in its volatile oil. Brandy contains $\frac{1}{3}$, $\frac{1}{2}$ alcohol, or even more. A part of this is evaporated in the lungs, and perhaps also on the surface of the skin. And in this way, the tension of the expired air—and therefore its volume (§ 187 *et seq.*)—is increased.

342. Infusions or decoctions of tea, coffee, and chocolate, the different kinds of broth, and milk — which is the most natural of all drinks — all operate by means of the various solid compounds dissolved in them. But our present chemistry is insufficient for a clear explanation of their influence. Accidental experience is here more successful than all the efforts of science.

343. The beans of coffee (*Coffea arabica*), together with the leaves of the Chinese tea (*Thea bohea*), and of the Paraguay tea (*Ilex paraguaiensis*, St. Hilaire; *I. gongonha*, Martius) drunk in South America, all contain an alkaloid which has the same ultimate composition. Both thein and caffein yield $C_{16}H_{10}N_4O_4$: so that both contain 49·3 per cent carbon, 5·2 hydrogen, 29·1 nitrogen, and 16·4 oxygen. Some have wished to deduce the peculiar effects of these drinks from the large amount of nitrogen contained in their alkaloids. But we shall hereafter mention facts which teach, that the mere quantity of nitrogen affords no measure of the influence which a particular kind of aliment may exert. It is probable that the action of cocoa, the seed of *Theobroma cacao*, which is made use of in the preparation of chocolate, is referable to its albumen (16·7 per cent), its starch (10·9), its oil, or the cocoa butter (53·1 per cent), and

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the alkaloid it contains. The latter, which is called theobromin ($C_9H_{10}N_3O_2$), yields 35 per cent of nitrogen.

344. Meat-broth which has been obtained by gradually raising the heat, and which has been freed from most of the coagulated albumen by careful skimming, contains the following substances:—lactic acid (§ 304), inosic acid ($C_{10}H_6N_2O_{10}+HO$), glutin (§ 317), tritoxide of protein ($C_{48}H_{38}N_6O_{19}$), kreatin (§ 319), kreatinin (§ 319), and about one-fourth of an ashy residuum, four-fifths of which is soluble in water. By this process the meat is so completely extracted as to be rendered quite tasteless. But if flesh is placed at once in boiling water, the superficial stratum of coagulated albumen hinders the complete action of the fluid: and the soup loses what the meat gains in flavour.

345. What are called soup- or meat-lozenges consist, for the most part, of gelatin (§ 317). But since this substance forms only a small constituent of strong meat-broth, it is evident that their solution cannot be an efficient substitute for a strong soup. Hence they only subserve those nutritional purposes to which a solution of gelatin would suffice.

346. We shall hereafter see that the exclusive use of azotized or non-azotized aliments is as little able to maintain the body as a supply of merely inorganic matter. Its requirements can only be satisfied by a proper mixture of different constituents, in a form which renders them accessible to the existing forces of the organism. These conditions are beautifully fulfilled by the milk which nature furnishes to the sucking animal. Its casein represents the albuminous substances; its sugar of milk, the hydrates of carbon; its butter, the fatty matters; and its ashy compounds, those mineral bodies which are independently necessary, or are usually introduced as a relishing addition to the food.

347. The vegetable aliments are the means of introducing a large quantity of the hydrates of carbon, such as starch, and the different kinds of sugar. But these combinations do not, as such, form permanent constituents of the solid animal tissues. They undergo a combustion into carbonic acid and water; or exist as soluble bodies in particular fluids, such as the blood, the bile, and the urine; or perhaps contribute, by means of their elementary constituents, to the production of other substances. In their original form, they are incapable of affording a permanent foundation for the chemical construction of the animal tissues.

348. The starch granules (Tab. I., Fig. XVII., *a*), such as are deposited in the cells of potatoes, and many other vegetables, are unchanged by cold water. But when treated with hot water, they form a paste which is converted into dextrin by sulphuric acid, or by the fermentative process (§ 173), and is thence easily transformed into grape sugar. These phenomena sufficiently explain why those kinds of food which contain most starch (such as potatoes, flour, sago, and arrowroot), are exposed to

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the influence of warm water, and why flour is subjected to a determinate process of fermentation before being eaten as bread.

349. The cellulose ($C_{24} H_{21} O_{21}$) so closely related to starch, and which is contained in the walls of vegetable cells, may for the most part be so changed by the action of sulphuric acid, as to offer with iodine a colour quite as striking as that of starch itself. But notwithstanding this, the walls of the different solid vegetable tissues behave very differently to the digestive fluids. Dense woody cells, such as occur in the stones of cherries, plums, and apricots, or in the epidermis of the stalks and leaves, can pass unchanged through the whole alimentary canal. Indeed, they may be said to seal up their contents hermetically, and thus render them useless to the body. On the other hand, more yielding vegetable membranes are sooner or later overcome. But it is questionable whether this contrast may not be due to differences in their chemistry, as well as to the mere physical circumstances of their aggregation.

350. Pectin or vegetable gelatin, and the pectic acid which is produced from it by alkalies ($C_{12} H_8 O_{10}$), occurs in juicy fruits, stalks, and roots. It appears to be closely related to the preceding substances, and to yield, like the hydrates of carbon, materials for nutrition rather than for development. The same remark applies to the vegetable mucus ($C_{24} H_{10} O_{19}$) which is contained in saloop and similar drinks.

351. From the destiny of grape-sugar, which is either introduced as such into the alimentary canal or produced here from cane-sugar, it seems impossible that it can be of more than transitory importance to the organism. If present in too large a quantity, a part of it may be given off in the urine. At other times it is metamorphosed or destroyed by processes of fermentation. The vinous fermentation (§ 325) leads to the formation of alcohol and carbonic acid; the mucous to that of lactic acid (§ 325), mannite ($C_8 H_9 O_8$), and a gum-like mass; and the butyric fermentation to that of carbonic acid, hydrogen, and butyric acid,—which latter can be obtained from lactic acid with the aid of water (§ 326).

352. The digestibility of fat, like that of cellulose, depends partly on its mode of aggregation, its fusibility, and the quantity which is introduced at once. Thus, under unfavourable circumstances, masses of fat may be discharged with the fæces. Where this is not the case, the fat may either undergo combustion, or may be deposited in the tissues.

353. Albumen, fibrin, and casein, are introduced in the fluid or solid form with many kinds of animal food. Although they constitute the essential conditions of maintenance and growth, still their usefulness is also dependent on the form in which they are aggregated, and the various circumstances which are connected herewith. The hard albumen of boiled eggs is overcome with more difficulty than when it is in a fluid or dissolved state. The fibres of meat sometimes partially

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defy the digestive powers. And hard casein always offers a considerable obstacle.

354. Theoretically, the blood ought to constitute one of the very best varieties of food, since it could most easily replace that mixture in our body from which all the excretions proceed. But dietetic experience, or, in other words, the instinct of selection, rather contradicts than supports this supposition. Blood itself is rarely made use of as food. Certainly blood-puddings are by no means so easy of digestion, as one might at first sight expect. The masses of coagulated fibrin may present many obstacles to the process. And it is possible that the solution of fibrin which the stomach would contain might lead to metamorphoses which would partially neutralize its usefulness. Besides, the small proportion of fat contained in the blood (·1 to ·33 per cent of the fresh fluid) allows the azotized constituents too great a preponderance. If the entire mass contains 53·6 per cent of carbon, 7·6 hydrogen, 15·8 nitrogen, and 23·0 oxygen, its composition approximates to that of the pure albuminous substances, which are unable to nourish the organism without some foreign admixture (§ 346). It is true that meat which has been cleaned from all visible fat exhibits an elementary composition which is very similar to this (53·4 per cent carbon, 7·9 hydrogen, 15·7 nitrogen, and 23·0 oxygen). But we generally eat it with the masses of fat attached to it, and with other compensative sauces or seasonings. In addition to this, it contains more potash and magnesia, while the blood contains more soda and lime.

355. The preparation and mixture of the different alimentary matters exercises an important influence on their dietetic value. But while instinct often leads us to very suitable combinations, hyper-civilization, on the other hand, gives us particular arrangements, which are not so much founded upon gustative pleasure as upon certain prevailing fashions to which the individual gradually has to conform.

356. As already mentioned, there are natural reasons for our mixing a food which is rich in starch—such as potatoes or bread—with salt or butter. The different acidulous salads, powerful condiments such as pepper or mustard, and alcoholic drinks, are intended to sustain the stomach in digesting substances not easily overcome; and the coffee without milk which is taken after dinner, tends to counteract the disadvantageous influence which distention of the stomach is capable of exerting on the functions of the brain. The mode of preparation has also an important influence in determining the nutritive properties of meat. The completely sodden beef which has been, so to speak, sacrificed for the good of the soup, is in a state much less favourable to digestion than a softer meat which has been more moderately boiled (§ 344). The high temperature made use of in roasting meat envelopes it in a husk of coagulated albumen, which prevents the exit of many other matters, and

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so keeps together all the compounds which belong to the meat. But the empyreumatic products which are at the same time developed, and especially the denser mode of aggregation which this mode of preparation produces, necessitate stronger digestive powers. Veal yields to boiling more than twice as much gelatine as beef. Hitherto, however, chemical research affords no sufficient explanation of the difficulty with which the flesh of many birds, amphibia, fish, and crustaceans is digested.

357. Since, as a rule, animal food is more easily and completely digested than vegetable, we also find that, generally speaking, the herbivora consume much more than the carnivora. And this often causes them also to consume greater quantities of drink.

A mare weighing 938 lbs. received daily 22 lbs. of hay, 4½ lbs. of oats, and 66 lbs. of water. Thus the solid food formed 1-35th, and the fluid 1-14th, or the total 1-10th of the weight of the body. The fæces of a tolerably well nourished horse amounted to from 110 to 132 lbs., and those of an animal which had fasted some time before death, 77 lbs. The residuum of the food thus forms from 1-8th to 1-12th of the weight of the body. The daily requirements of a milch cow amount to 1-30th of the corporeal weight in hay, and 2-15ths in water, or 1-6th in both together. The contents of a rabbit's intestine amounted to ·75 lbs., and nearly 1-4th of its weight. While that of a cat which weighed 6·29 lbs., and which had fasted, only amounted to $\frac{1}{81}$ of its mass. A second cat, of 8·38 lbs., whose stomach was full of half digested flesh, yielded $\frac{1}{21}$ to $\frac{1}{22}$.

This disadvantage under which the herbivora generally suffer depends upon three causes. Plants generally contain but small quantities of azotized alimentary substances; so that they require to be taken in larger quantity. Their digestion is usually less complete and slower; so that the quantity of residue present at any one time may therefore be considerably greater. The dense woody masses which pass through unaffected not unfrequently hermetically enclose other nutritious constituents. And, as a third reason for a greater amount of food, we may add, that many albuminous compounds which are free, are nevertheless not overcome.

358. As man sustains himself by a mixed diet, similar differences are repeated in these different modes of nutrition. But we must not overlook the fact, that two circumstances generally diminish the disadvantage of vegetable food. One is, that man for the most part only eats roots, stalks, leaves, or fruits, in which the softer tissues predominate. Another is, that the preparatory cooking, and the condiments added, often make it more digestible than it would otherwise be.

359. If the feelings of hunger and thirst are not pacified, they disappear after some time, to return subsequently with heightened force; and if the fasting state continues without interruption, man perishes, before

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his body has lost one half of its weight, or has become perceptibly drier to the eye.

360. So far as we know, the adult may live about three weeks without any food. And if, while all solid food is withheld, drinks which contain no proper nutritional substances are made use of, this term may possibly be extended to eight or ten weeks. Children are less able to sustain a deficiency of food than adults.

361. Animals which are fed on unsuitable or non-azotized compounds, such as sugar or albuminous substances, also perish of inanition,—*i.e.*, with symptoms similar to those of starvation. And if only supplied with a food which contains no lime, its injurious effects are in time exhibited as degenerations of the tissues, such as, for instance, local softenings of the bones. We shall return to these phenomena in speaking of nutrition.

362. The teeth exhibit three chief differences of form,—the incisor or cutting teeth, the canine or eye teeth, and the molar or grinding teeth. These differences of shape are associated with similar varieties of function. The crown or free part of every cutting tooth (*a*, Fig. 63) has the shape of a knife edge, which renders it best adapted to the biting off of solid masses. The canine tooth is prolonged above into a point (*a*, Fig. 64): so that it is driven like a wedge into solid masses. Finally, the back teeth have broad and forked chewing surfaces (*a*, Fig. 65), which are chiefly used for crushing, and, when moved laterally, for grinding. The name of molar teeth refers to this second property, which is less prominent in man than in many other mammals.

363. Many of the most important peculiarities of the teeth are explained by their mechanical arrangement. Their long roots, *b*, Figs. 63, 64, 65, are implanted like nails in the alveolar compartments of the jaw.

FIG. 63.

FIG. 64.

FIG. 65.

The numerous nerves of sensation supplied to them are removed into the tooth sac which occupies their interior, so as to avoid all pain from the pressure exerted upon their surface. Their fundamental structure is the dentine, or true tooth substance, which is characterized by fibres or tubules (Tab. III. Fig. XLIX. *a b*). The enamel, which is composed of densely interwoven fibres (Id. *b c*), surrounds the entire crown of the tooth,

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(*a* Figs. 63, 64, 65). The nature and arrangement of its elements endow it with more hardness than any other animal substance. The structure of these essentially dental tissues differs considerably from that of the bones. It is only the thin layer of cement that clothes the roots of the human teeth, and attains a more considerable development in many mammalia, which so far resembles bone, as to possess true corpuscles in man, and medullary canals in the horse (Tab. III. Fig. L.).

364. Most of the disorders of the teeth begin in the enamel. It is easily broken by violent mechanical force. Acids corrode it, even when they are considerably diluted. When they set the teeth on edge, it is probable that small quantities penetrate even to the dental sac. And if the dentine has lost its covering of enamel, it seems unable to maintain itself: the tooth becomes hollow at the corresponding spot, and subsequently the crown gradually perishes.

365. In the act of mastication the lower jaw (*a i*, Fig. 66) is pressed against the immovable upper one (*k g*). Since the upper and lower rows of teeth are arranged symmetrically, it is only the corresponding masticatory surfaces of opposed teeth which work upon each other. The

FIG. 66.

cutting teeth thus operate like the blades of a pair of scissors; and the canine teeth like wedges, which are approximated to each other in opposite directions. The molar teeth are irregular surfaces of pressure, the depressions of one set fitting into the corresponding depressions of the other.

366. The muscles of mastication — the temporal, masseter, and pterygoid —make use of the immovable skull as their point of fixation. They thus draw the lower jaw in directions determined by the course of their

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fibres. For instance, the temporal muscle is attached to the temporal fossa (*d*, Fig. 66), while its tendon passes to the coronary process (*b*) of the lower jaw (*a i*). Hence it draws in the direction *d b*, and so raises the lower jaw. On this account the temples are visibly swollen in the act of mastication; and become painful when this process has been too long continued.

367. Mastication is, in man, for the most part limited to the elevation and depression of the lower jaw; but we are also able to move it forwards and backwards, as well as sideways. Still the latter movements have a very subordinate importance in us compared with many mammalia,—for instance, with the ruminants, who are obliged to bruise the tough stalks of plants much more energetically.

368. The highly tactile as well as movable tongue regulates different alterations of position, which are necessary to the act of mastication, and, in some extent, to that of drinking. When the cutting teeth have severed a bite, the tongue presses it against the hard palate, and slides it between the molar teeth, in order that it may be here bruised more completely. When these have done their duty, the masticated mass is reconducted by the pressure of the cheeks to the surface of the tongue. This now plays a determinate part. Its anterior portion presses itself firmly against the hard palate, so as to render it impossible that the food should pass in this direction. Its remaining portions force the solid mass backwards, so that it glides over the root of the tongue towards the entrance into the throat.

369. Drinks may be poured in so as to flow spontaneously into the pharynx. In this case the tongue is often hollowed out on its surface, so as to form a sort of furrow, which serves to conduct the fluid. It frequently happens that we suck in fluids in the act of drinking. We dilate the cavity of the mouth; and the enlargement of this space diminishes the tension of its aeriform contents; so that the external atmospheric pressure (§ 84) drives in a corresponding quantity of fluid. When this has occurred, the tongue again presses against the hard palate, and conducts the whole safely towards the throat.

370. Anatomy can only take satisfactory cognizance of those larger groups of contractile tissue which cause this infinitely variable play of muscular action. Their several fibres, and especially those of the lingualis or proper muscle of the tongue (*b*, Fig. 67), and of the other muscles which radiate into it, are so densely interwoven with each other as to allow of the most manifold and intricate combinations.

371. The proper lingual muscle is itself not fixed to any bone. Hence it is capable of acting in the most different way, according as it makes use of this or that soft part as its point of origin. The remaining contractile structures are divisible into two classes. One, which includes the genio-glossus (*a*, Fig. 67) and stylo-glossus (*c*, Fig. 67), is

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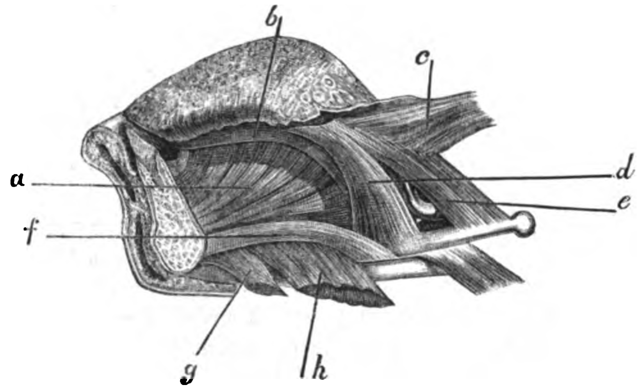
fixed to parts which are comparatively immovable, such as the lower jaw and styloid process; while the other, the hyoglossus (*d e*, Fig. 67), is attached to the hyoid bone, a part which is capable of being again acted

FIG. 67.



upon by other muscles. It is easy to see how this will have an important reaction on the tongue itself.

372. When the tongue (*c*, Fig. 68) has urged onward the alimentary bolus as far as its own root, it shuts off all return by pressing its middle portion against the hard palate (*b*). And when its posterior part takes up this action, the mass is forced to glide onwards over its slippery mucous surface, under the soft palate (*d*), into the cavity of the pharynx behind it. Hence it passes straight into the commencement of the œsophagus (*l*). But it there meets with other apertures, into which, without especial care, it might easily stray. The pharyngeal openings of the Eustachian tubes, the two posterior apertures of the nasal fossa (*f*), and the glottis (*i*), on this account demand some attention.

373. The mouths of the Eustachian tubes are situated so high up, they are so small, and so obliquely slit, and their opposed margins so closely approximated, that they rarely cause any disturbance. At most, fluids or semi-solid fragments can only be wedged into their commencement in the act of vomiting, and even here only under extraordinary circumstances.

374. When the epiglottis (*h*, Fig. 68) stands upright, as shown in the accompanying engraving from the dead subject, the glottis is certainly exposed. But the same movement of the tongue which impels the bolus of food towards the cavity of the pharynx, has the immediate effect of bending over the margins of the epiglottis, so as to form a sort of viaduct, over which the food and drink glide. But since at the same time the glottis is narrowed and the thyroid cartilage raised, while the neighbouring

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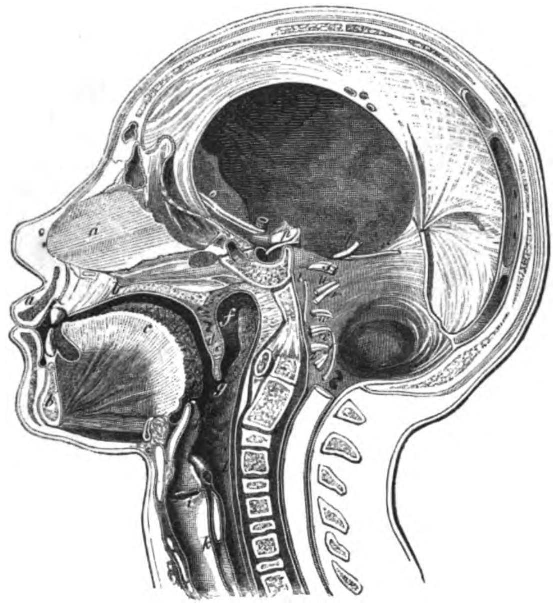
folds of mucous membrane are brought into contact with each other, we can understand how men can swallow without impediment, even after the loss of the epiglottis. Nevertheless the glottis often gives rise to

FIG. 68.



some embarrassment even in health. If we speak or laugh during the act of swallowing, the fluid or solid easily goes the wrong way, *i.e.*, a part of the fluid or semifluid descending mass goes through the glottis (*i*) into the lower part of the larynx (*k*). And the irritability of the mucous membrane of this part immediately gives rise to the convulsive expiratory movements of cough.

375. The soft palate is proportionally most altered at the instant of deglutition. Its office is to prevent anything from passing into the nasal cavity; and thus the chief object of its movement is to hinder the alimentary bolus from entering the upper part of the cavity of the pharynx at *g*.

376. The condition of these parts in a state of rest, may be seen in Fig. 69. By holding the tongue flat, the several structures at the entrance of the throat may be seen before a mirror to tolerable advantage. Under such circumstances we may recognize the two anterior or palato-glossal arches (*b b'*), and the two posterior or palato-pharyngeal (*c c'*). The free margins of the latter project rather more internally than those of the former. The curtain of the soft plate (*d*) bears, in the middle line, the dependent uvula (*e*). The tonsils, *ff'*, lie at the bottom of

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the interspaces between the anterior and posterior palatine arches (*b b′* and *c c′*).

377. If while we make movements of swallowing, we at the same time press the swelling tongue downwards with the finger, so as to get an

FIG. 69.

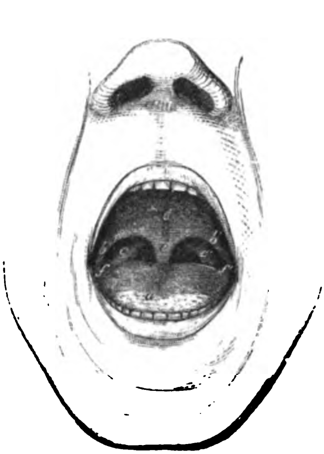
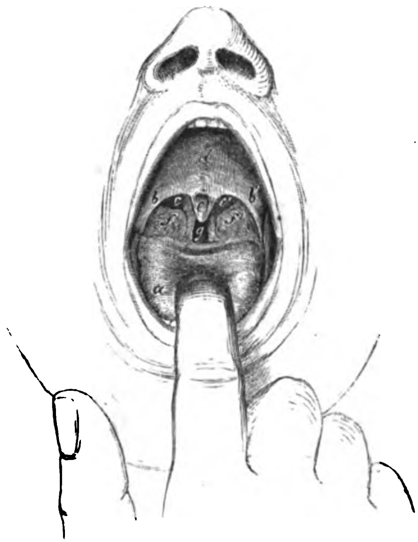


FIG. 70.



unimpeded view, we get a condition such as that represented in Fig. 70. The anterior palatine arches, *b b′*, are drawn widely outwards, while the posterior, *c c′*, are shoved inwards; so that the interval which formerly existed between them is diminished to the aperture *g*. And if their internal margins (*c* and *c′*) are brought into contact, even this altogether disappears. The uvula (*e*) may help to fill up the interspace represented above. But since the anterior arches deviate outwards, the intervals between them and the posterior are dilated, so as to uncover a large additional portion of the surface of the tonsils (*f f′*). This not only assists the passage of the bolus, but ensures its wiping away the mucus adherent to the tonsils, so as to allow of its subsequently gliding more easily away (§ 79 *et seq.*).

378. Sometimes disease or injury of the neighbouring structures lays bare the organs concerned in deglutition. Cases of this kind have been carefully examined by Bidder, Kobelt, and Noeggerath. They complete the views which anatomy and experimental physiology have already led us to adopt. In such cases it may be seen that the curtain of the palate, which in a state of rest hangs obliquely (*d*, Fig. 68, p. 125), is strongly directed backwards, and strives to come into contact with the posterior wall of the pharynx, which is opposite to it. The point of the

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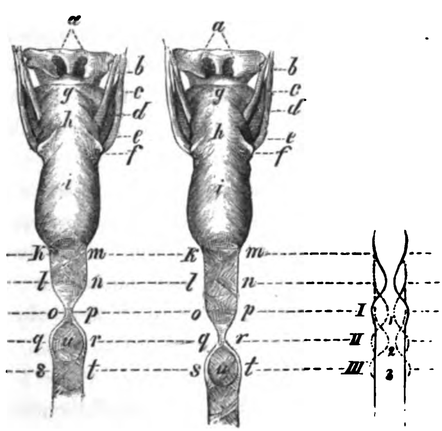
uvula does indeed touch it. But since the posterior palatine arches (*c c'*, Fig. 70) are so strongly impelled inwards that the space *g* is obliterated, they form, together with the soft palate, an oblique party-wall, which is directed downwards and backwards, so as to cut off the lower part of the pharynx (*f*) from the upper (*g*, Fig. 68). Hence the food and drink necessarily take the proper path (*g l*).

379. The constrictor muscles of the pharynx (*g h i*, Fig. 71), and especially the middle (*h*) and the lower one (*i*), impel the bolus into the œsophagus or gullet, *m t*; the muscular coat of which tube drives it swiftly downwards towards the stomach. And since the œsophagus lies close to the vertebral column, the pressure of a very hard and large alimentary bolus excites a sensation of pain, which is referred to the bodies of the vertebræ.

380. The movement of the several parts of the alimentary canal may proceed in a peristaltic or an anti-peristaltic* manner. In the first case, it passes from the mouth towards the anus, and in the latter, takes the reverse course. And since, in this movement, every portion is alternately contracted and dilated, and the change is propagated successively from place to place, undulations are produced, which glide onward at a quicker or slower rate. The similarity of these to the movements of a worm leads to the term "vermicular" being applied to them.

381. Let us imagine *a* (Fig. 71) to be the posterior apertures of the nasal fossæ, *g h i* the pharynx with its constrictors, *k m* the place where

FIG. 71. FIG. 72. FIG. 73.



it merges into the œsophagus, and *u* a bolus which has already been impelled a short distance. The upper part of the œsophagus, *k l m n*, is then so widely relaxed as to have resumed its former state of rest; while, on the other hand, *l o q* and *n p r* are so contracted, that *o* and *p* are nearly or quite in contact. As long as this state lasts, the bolus *u*

* See note to § 399.

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cannot return with an anti-peristaltic movement towards *l n*. While, if *o q* and *p r* contract still more strongly, and hence tend to approximate *q* and *r* to each other, *u* must move peristaltically towards *s t*, if the necessary force be present.

Let us suppose that this the first stage of its alteration of position is completed, so that *q r* can contract unimpeded, so as to meet as shown in Fig. 72. They will now play the same part as *o* and *p* in the first instance. While *o* and *p*, which now have nothing to shut off, relax like *h* and *n*. And *q s* and *r t* contract like *o q* and *p r* formerly did: that is, they urge the bolus onward in the peristaltic direction, and then come into mutual contact. And as the same process recurs at every point of the œsophagus, the bolus finally glides into the stomach.

382. These circumstances may be illustrated by the diagram in Fig. 73. If we imagine the point of greatest contraction is in the first instant at 1, while the maximum of relaxation would correspond to II, the contraction must descend from 1 to II,—from the deepest point of the valley to the highest point of the ridge which the undulation forms. The circumstances are correspondingly altered from point to point. The maximum of contraction is then somewhat below 1, and that of relaxation a little below II. At a later period, the former is at 2, corresponding to II, while the latter is at III. It is easy to see that from I to 2 is half the length of a wave; and from I to III is a whole one. The velocity with which the wave and the bolus descend to the stomach is determined by the rapidity with which these alternate contractions and relaxations are propagated. It is so great, that the undulations appear to succeed each other instantaneously; but it is yet slow enough to allow the eye to follow them. From facts which we shall learn in the phenomena of vision we are enabled to conclude, that each half of an undulation demands at least rather more than one-third of a second.

383. The movement of the œsophagus mainly depends on the trunk of the vagus nerve, on the roots of this, and of the sympathetic nerve, and on the medulla oblongata, together with the neighbouring upper part of the spinal chord. The vagus of one side suffices to conditionate these alternate undulations. If a long segment of the tube is paralyzed the undulations are limited by its upper extremity.

384. In the erect or sitting posture the food,—and *à fortiori* the drink,—descends into the stomach by virtue of its gravity; for we have already seen that the contact of the œsophageal walls offers no efficient resistance. The gradual decrease of contraction, from the place of perfect occlusion to that of greatest relaxation, not only furnishes the force which urges the bolus onwards, but also that by which it is grasped and retained. But even if the nerves of the œsophagus be paralyzed from any cause, drinks can still pass downwards under the impulse of their gravity. If the stomach is at the same time filled with gases, or if these

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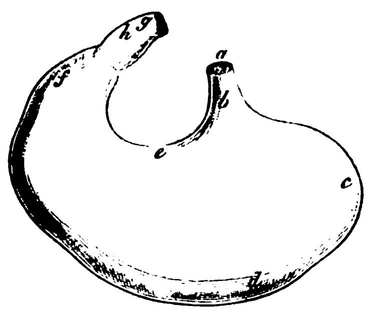
limit the fluid or semifluid mass into which the descending fluid falls, we hear a sound as when a stone is dropped into a well. This sonorous deglutition often precedes death by a few days.

385. While the transit of the food through the pharynx and œsophagus is accomplished as quickly as possible, it remains in the stomach for a much longer period, in order to be exposed to the action of the gastric juice. In this latter organ we meet with an alternating action of the muscular fibres, the object of which is easily conjectured, although its details cannot be satisfactorily explained. For though experiment proves that movements of the stomach may be excited by the vagus and sympathetic nerves, as well as by the medulla oblongata, the upper part of the spinal chord, and the brain anteriorly to it,—still no artificial irritation enables us to reproduce that determinate alternation of contraction and relaxation, which probably occurs during life.

386. The lowest part of the œsophagus (*a*, Fig. 74) presses the solid food with such force into the cardiac extremity of the stomach (*b*), that the mucous membrane is sometimes visibly protruded. When this has happened, the cardiac orifice shuts. And if the pylorus (*f*, Fig. 74) does not yield, while, at the same time, the unstriped muscular fibres contract forcibly, the food will necessarily be driven forwards, and will even be made to revolve in a curved course around one of the axes of the organ. But since the external atmospheric pressure compels all the abdominal viscera into the smallest possible dimensions, the food and the stomach are everywhere brought into perfect contact, so long as this mutual relation is not partially impeded by liquids or elastic fluids which occupy a proportional space.

FIG. 74.



387. Fluids which do not require a protracted stay in the stomach, and are incompletely absorbed here, may be very quickly passed on to the duodenum. They are transmitted from the cardia (*b*) through the cardiac pouch (*c*) along the middle portion (*d e*) towards the pylorus (*f*), and thence through the pyloric orifice (*h*) into the superior transverse portion of the duodenum. But semifluid or solid masses which have to undergo a delay in the stomach give rise to more complicated circumstances. We shall see that the several segments of all tubes provided with unstriped fibre exhibit certain intervals of rest and movement, —definite kinds of contraction and relaxation,—in their different constituents. It is probable that the action of the stomach is also governed by such laws.

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388. On swallowing a mixture of solid and fluid food, it would seem that the latter constituents, rather than the former, pass from the cardiac pouch (*c*) to the pyloric segment (*f*); and, for the most part, along the greater curvature (*d*). Solid masses of no great bulk take the same course at a later period; but if they distend the stomach more powerfully, or if this organ, from any cause, takes on another kind of activity, they may be rotated in a more or less complete circle. In such a case they are passed from the cardia (*c*) around the great curvature (*d*) to the pylorus (*f*); and are also rotated about the transverse or oblique axis of the organ in an arched direction from *d* to *e*. The object of this complicated movement is to mix the alimentary bolus as intimately as possible with the gastric juice occupying the mucous surface of the stomach. When a superficial layer of food has thus been converted into a semifluid mixture, into chyme, a general movement directed towards the pylorus easily strips it off, and, on the opening of the pyloric valve at *h*, urges it into the duodenum. The removal of this first layer of chyme lays bare a fresh layer of food, on which the process is repeated. Finally, a time comes when the alimentary bolus is so diminished, as to offer no obstacle of any importance to the passage of the whole into the duodenum.

389. In the stomachs of recently killed animals deep furrows or constrictions are frequently remarked. They mostly extend from the greater to the lesser curvature, or from *d* to *e*, and are caused by muscular contraction. Vermicular contractions may exist in their neighbourhood, or may even glide over them, without causing any alteration in their appearance.

390. It not unfrequently happens that a dog whose stomach has been laid bare gradually swallows considerable quantities of air, so that the organ becomes visibly inflated. But the increased bulk of the stomach in no way depends on an active and muscular extension of its walls.

391. Normal digestion requires that the contents of the stomach should sooner or later be impelled towards the duodenum, or in the peristaltic direction. But it may happen that they return towards the œsophagus, or in the antiperistaltic course. Such an improper movement of gases, or of small quantities of semifluid substances, is the cause of eructation; while larger quantities of food or drink cause vomiting.

392. The over-distended stomach is in this way relieved of a part of the surplus contents. Too great a pressure of the abdominal walls, such as often occurs in violent cough, sometimes leads to this result. But the usual cause of vomiting lies in the condition of the nerves which rule the structures we are now considering. Hence the movements of vomiting are most frequently excited by immediate or mediate irritation of the mucous membrane of the stomach, and of the nerves which supply it; or

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by certain substances,—such as ipecacuan or tartar emetic,—which have a similar effect when taken into the blood. The sensations which precede vomiting may be regarded as an expression of that shock,—whether tension or struggle,—which announces itself in the molecular condition of the nervous system before producing the explosion itself.

393. The abdominal pressure, which has an important influence on the evacuation of the bladder, uterus, and large intestine, plays a very essential part in ordinary vomiting, the mechanism of which may be explained by a reference to Fig. 9, p. 34.

This wood-cut represents the condition of these parts as seen in the dead subject. In this state the diaphragm ($m\,n\,o$) shows a convexity towards the cavity of the thorax; while the relaxed abdominal walls ($\epsilon\,\vartheta\,\eta$) fall more or less forwards. These two muscular structures play antagonist parts in the ordinary movements of respiration. The diaphragm contracts during inspiration, and the muscular wall of the abdomen during expiration. The shortening of the diaphragm reduces it to a flattened surface which seeks to occupy the direct line $m\,o$, instead of $m\,n\,o$; so that the space $m\,n\,o$ is gained by the thoracic, and lost by the abdominal cavity. But as the relaxed abdominal wall, $\epsilon\,\vartheta\,\eta$, yields, the viscera of the belly are impelled forwards, the wall being carried before them in a corresponding degree. In the expiration which follows the diaphragm is relaxed, while the abdominal walls contract. And these taking up the line $\epsilon\,\eta$, instead of $\epsilon\,\vartheta\,\eta$, the displacement is repeated in the opposite direction; so that the abdominal cavity regains its former position, the diaphragm being pressed upwards into the thorax at $m\,n\,o$. Thus ordinary breathing displaces the intestines, but does not furnish a pressure sufficient to expel any part of their contents.

Abdominal pressure is due to the diaphragm and abdominal muscles contracting simultaneously, instead of singly, as during inspiration and expiration. The abdominal cavity is thus at once diminished by the spaces $m\,o\,n$ and $\epsilon\,\vartheta\,\eta$, these muscles exerting a pressure which is only rendered unimpeded by some of the contents of this cavity making place. It depends on the accompanying circumstances which orifice of exit is thrown open, so as to allow of this object being attained. If it is the bladder, x, which yields, the urine is evacuated. If it is the uterus, w, which brings about the balance, the ovum or fœtus which it contains is expelled. Under corresponding conditions the fæces are expelled from the rectum. And finally, if the pylorus be shut, and the cardia g open, a certain quantity of the contents of the stomach will be impelled upwards into the œsophagus.

394. From hence it is easy to see what an important part the abdominal pressure plays in the act of vomiting. And even if we imagine the pylorus incompletely closed, still, in spite of this, the whole or the greater part of the gastric contents will be expelled into the œsophagus,

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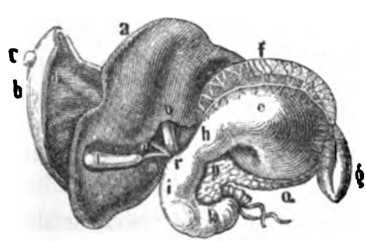
since this alone can satisfy the demands made by the diminished size of the abdominal cavity.

395. The upward impulse produced by the abdominal pressure is stronger, the greater the force with which the diaphragm and abdominal muscles simultaneously contract, and the less the resistance which is offered by that portion of canal intervening between the stomach and the mouth. In vivisected animals, the violent and sudden abdominal pressure may be seen to impel the vomited mass at one stroke to the mouth, without the association of any antiperistaltic undulations of the œsophagus. But, according to Budge, where the act of vomiting is slower, this assistance is added. The soft palate and the palatine arches are also carried upwards into the pharynx, and hence tend to shut off the nasal fossæ and Eustachian tubes (§ 377); but the velocity of the rising mass is not unfrequently so great, that there is no time for the completion of this effort, so that certain quantities of the vomited mass pass through the nasal fossæ, and emerge from the nostrils. Sneezing then follows.

396. In an experiment on a living animal, in which Magendie substituted a pig's bladder filled with fluid for the stomach, and reunited the abdominal coverings by suture, he found that the abdominal pressure sufficed to expel its contents into the mouth. But this does not prove that the stomach is always inactive during vomiting. Since animals whose stomachs are exterior to the abdominal cavity can still vomit fluids, it is evident that we need not regard the abdominal pressure as the only cause of vomiting. Indeed, this act has sometimes been observed to be preceded and accompanied by a gastric movement, which sets out from the pylorus (*f*, Fig. 74, p. 129), and takes a course towards the cardiac pouch (*c*). This may assist to reverse the course of the matters vomited. But it may also be imagined that it tends to occlude the pyloric portion, in order that everything may be impelled towards the œsophagus.

397. When the chyme has passed through the pyloric aperture, it reaches the superior transverse portion of the duodenum, which is seen somewhat distorted at *h*, Fig. 75, on account of the stomach (*e*) being drawn upwards. It then passes into the descending or vertical part, where it mixes with the bile and pancreatic fluid. The former secretion may flow downwards either by the hepatic (*n*) duct, or by the cystic (*m*) from the gall-bladder (*l*). Both of these canals are united to form the ductus communis choledochus, or common biliary duct, which is visible at *r*, and which penetrates the descending duodenum close to the excretory duct

FIG. 75.



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of the pancreas. These efferent canals of the liver and pancreas pass for a certain distance between the muscular fibres of the duodenum, before they open on an elevation of mucous membrane in the cavity of the intestine. They are thus closed at the instant in which their neighbouring muscular fibres contract; and are protected in this way from any disturbing reflux of fluid chyme. Their own secretions only pass into the duodenum at certain suitable times.

398. The small intestines (*s*, Fig. 9, p. 34) gradually drive their contents onward. But this peristaltic movement is slower and more interrupted than might be expected from many experiments instituted on dead animals.

If we open the abdominal cavity of a suffocated rabbit, we generally find a vigorous and tempestuous movement going on in many parts of the small intestines. But it would be a great mistake to conclude that a similar storm of peristalsis obtains in the living human subject. If we examine the intestines of a living rabbit we find them much more tranquil. The small intestine of mice which have been killed by the vapour of ether often exhibits not a trace of peristalsis, even under the influence of the electro-magnetic machine. In surgical and obstetric operations—as, for instance, in hernia or the cæsarean section—it occasionally happens that some loops of small intestine are exposed; but they are either altogether still, or at anyrate their contractions are less vigorous than those sometimes seen in criminals after execution. And persons who have a fistula of the small intestine after an operation for hernia (*i.e.* who have in the intestine an opening which passes through the wall of the belly to the outside) only pass fluid fæcal matters at intervals. This fact affords a fresh corroboration to the statement that undigested food generally passes but slowly through the small intestine.

399. An examination of the dead rabbit proves that the peristaltic movements exhibit certain alternations of activity and repose. If *d a b c* Fig. 76, be a segment of small intestine, the vermicular movement will pass gradually from *d* to *c*, the contraction and relaxation moving onwards as in the œsophagus (§ 380), except that the undulations are slower and shorter. The movement is often arrested at *c*. But it not unfrequently begins anew at *d*, to pass through an equal, *d c*, a shorter, *a b*, or a longer, distance. Every undulatory contraction can drive the contents forwards either completely, or imperfectly, or not at all, according as the maximum force of contraction can produce a contact of opposite points in a transverse section of the tube, or can only approximate them to each other. And if we add to this that the vermicular contraction is not always peristaltic, but sometimes antiperistaltic,* it will follow, that

* It appears highly improbable that peristalsis is ever reversed in any part of the living intestinal canal, while the contractions here alluded to are so irregular, that the rule might almost be extended to the dead subject.—*Editor.*

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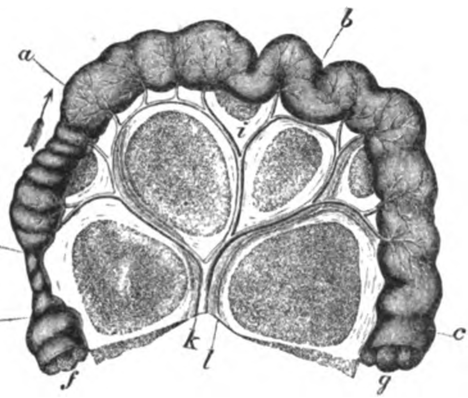
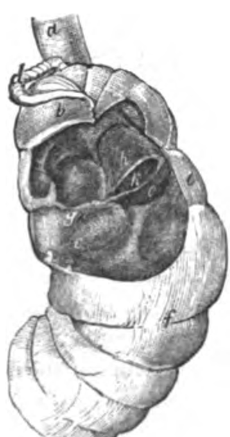
the contents of the small intestines of a recently killed rabbit are urged onwards more slowly than appears at first sight to be the case. And we have already seen that the velocity is still less in the living animal. Whether it is greater in the jejunum than in the ileum is at present unknown.

FIG. 76.



400. The commencement of the small intestine has its pyloric valve (*h*, Fig. 74, p. 129), which tends to prevent an antiperistaltic reflux of the chyme into the stomach. The end of the ileum (*a*, Fig. 77), possesses the ilio-cœcal valve, which executes a similar service. Under ordinary circumstances this renders it impossible that there should be any antiperistalsis of the contents of the cæcum (*b*) or the ascending colon (*c* and *f*) towards the small intestine (*a*); while on the other hand, it easily allows all substances present in *a* to pass through its fissure *k* towards *b* and *c*.

FIG. 77.



401. The pyloric valve forms a double fold of mucous membrane, which is almost levelled by the removal of the corresponding muscular bands. The ilio-cœcal valve (*h c*, Fig. 77) is formed by the peculiar mode in which the ileum (*a*) sinks into the common commencement of the cæcum (*b*) and the ascending colon (*f*). And if in the dead body we inject fluid in the direction from *f* towards *a*, *h c* is often so completely shut, that the corresponding portion of the large intestine bursts rather than allow the fluid to pass into the ileum. Something similar to this is generally repeated in the living subject. It is only in the most

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urgent cases that excrements pass into the small intestine and thence upwards. Hence the genuine fæcal vomiting—as distinguished from that apparently stercoraceous vomiting, by means of which the contents of the small intestine are discharged from the mouth—only occurs in those obstinate cases of strangulated hernia of the large intestine in which the exit per anum is immutably shut.

402. When the residue of the food contained in the ileum (*a*, Fig. 77) is impelled through the fissure (*k*) of the ilio-colic valve (*h c*), two ways are open, that toward the cæcum (*b*), and that towards the ascending colon (*f*). But it is probable that the muscular fibres here present have a definite mode of action. A large part of the food is frequently found in the cæcum; indeed, in well nourished herbivorous animals it is usually more or less thus distended. The vermiform appendix *d*, also receives alimentary matters. Its narrowness may be the cause of danger to life. For instance, a cherry-stone which has been swallowed now and then sticks fast in the vermiform appendix, and gives rise to inflammation and suppuration. And if this produces perforation, the fæcal matters pass into the abdominal cavity, and lead to an inflammation of the peritoneum which is generally fatal.

403. The remains of the food, after spending a certain time in the cæcum, subsequently enter the commencement of the colon: so that we have here a definite alternation of movement in two opposite directions.

404. The cæcum (*b*), the ascending (*f*, Fig. 77), the transverse (*l*, Fig. 9, p. 34), and the descending colon *u*, Fig. 9, possess greatly dilated pouches or sacculi (*e*, Fig. 77), constituting a kind of supplementary cavities, which increase the surface of contact, and retard the movement of the substances occupying their interior. The falciform folds (*g*, Fig. 77) which occupy the transverse constrictions of their interior have the same direct use as the valvulæ conniventes of the small intestine. They retard the advance of the substances which glide along their cavities, so that certain portions are confined between them. And since they are occupied by transverse or circular muscular fibres which take the same direction, they may occlude corresponding portions of the large intestine. It probably depends on the mechanism of the falciform fold *g* that the remains of the food *a* descending from the ileum pass first into the cæcum *b*, and not into the ascending colon, *f*. The longitudinal bands which are indicated at *f*, Fig. 77, and which proceed from an aggregation of the longitudinal muscular fibres, shorten the large intestine in a direction from the ileum towards the rectum: they can also to a certain extent depress it, and under many circumstances are capable of widening it.

405. On observing the movement of the large intestine in a newly killed rabbit, we find a recurrence of the same phenomena which we have already seen in the small intestine. We not unfrequently remark

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undulations, which pass more or less completely around it, and the effect of which on the contents seems to be quite superficial, so as not to drive them on to any visible extent. To this it may be added, that the movements during life are probably slower, and only return after certain intervals of rest: while the more solid fæcal masses present greater resistance, and the mechanical obstacles of the intestine itself are also greater. Hence it follows, that the forward movement of the large intestines is even slower than that of the small. The phenomena of constipation corroborate this view.

406. The uniformly cylindrical rectum (*y*, Fig. 9, p. 34) possesses a muscular coat which is of great proportional strength, and which, as far as the anus, is composed of unstriped fibres similar to those of the stomach and the small and large intestines. The movements which it exhibits in the newly killed animal, as a result of irritation of its nerves, are, however, essentially different from those of the remainder of the alimentary canal. It moves up and down by fits and starts, and sometimes the fæcal pellets are visibly expelled by the aid of a vigorous peristalsis. Finally, sections which have just emptied themselves may be seen to collapse, so as to prevent the reflux of the contents upwards.

407. The sigmoid flexure of the colon (*v*, Fig. 9, p. 34) which depends from a loop of mesentery, and through which the descending colon *t* passes into the rectum *y*, probably often serves as a receptacle of fæces. Its free attachment allows it to change its position according to its weight, while its curvature prevents too much being impelled at any one time from the colon into the rectum.

408. Since the lowest part of the rectum lies outside the cavity of the peritoneum *y*, Fig. 9, the less hindrance is offered by the pelvic structures, the more easily will the abdominal pressure (§ 393) urge the fæces towards the anus. And if these parts assist, the evacuation will be so much the more easily effected.

409. The peristaltic or impulsive movements of the rectum probably give rise to the feeling of necessity for an evacuation. Under certain abnormal conditions—for instance, in violent diarrhœas—it sometimes happens that a person feels compelled to go to stool every instant, but in spite of every exertion, is unable to evacuate anything, or, at most, only small quantities of fæces, mucus, or blood. It is the irritation of the mucous membrane of the rectum, and the movements of the terminal portion of the alimentary canal thus produced, that give rise to these deceptive sensations, which often continue in spite of all evidence to the contrary.

410. The movements proper to the rectum, in conjunction with the assistance given by the abdominal pressure, expel the fæces from the anus. The contractile structures here concerned do not act uninterruptedly: but contraction, relaxation, and rest, each have their sys-

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tematic influence. And the muscles of the pelvic outlet also take a determinate share, by means of which they assist the process.

411. It is probable that the external sphincter of the anus, which is provided with transversely striated fibres, is in a state of moderate contraction when no fæces are passing. But since a foreign body can penetrate the anus without meeting any great amount of resistance, it may be conjectured that the ordinary contraction of this circular muscle is inconsiderable. If large masses of fæces are to pass through, the sphincter yields: but if they are to be retained, it remains more energetically contracted.

412. The internal sphincter of the anus, which is composed of unstriped muscular fibres, and is only a greater aggregation of the circular fibres of the rectum, must obviously be relaxed at the instant the fæces pass. And by subsequently contracting it may either divide what has already passed from what remains, or may only generally prevent all exit.

413. The levator ani probably widens and shortens the rectum, and partially prevents the mucous membrane being prolapsed from its loose and yielding attachment. The influence which is exerted by the coccygeus and the transverse perineal muscles has yet to be established.

414. The chief object of the chemical phenomena of digestion consists in the solution, as far as possible, of those solid compounds which we receive in the food. Since it is only gaseous fluids or liquids which can enter the lymph or blood by way of diffusion (§ 129), many alimentary substances require to be liquefied in order to attain their object. It also follows that most drinks do not require any special process of digestion; so that the alimentary canal only affords them the means of transit. But it is by no means impossible that the chemical influences exerted by the different parts of the intestine are made use of to assist in the digestion of many fluid aliments.

415. Many drinks,—as, for instance, beer or coffee,—are mixtures of solid and fluid substances. Water containing much lime becomes turbid when mixed with the food. And milk, as we shall see, precipitates the greater part of its casein in the stomach. These solid substances will, therefore, require an additional process of solution, in order to their entering the blood. Broths, and similar drinks, contain many oil-drops, which only enter the chyle and the blood under the influence of a chemical process of digestion.

416. In order to dissolve the largest possible quantity of solid alimentary substances in the course of the intestinal canal, nature makes use of two methods. The first consists in a series of watery solutions, which are faintly acid or alkaline, contain certain salts and suitable organic compounds, and which have the ordinary temperature of the interior of the body,—viz. 98·6°, or rather more. All substances which are unable to resist these influences are at once liquefied. But as this method alone

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would not suffice, definite processes of metamorphosis are also induced, so as to form new and more soluble compounds. But they are not always carried to their utmost extent, since bodies less serviceable to the organism would be ultimately produced: on the contrary, their soluble first products are removed at once from the control of the alimentary canal.

417. As all the substances really alimentary belong to the vegetable or animal kingdom, fermentation and putrefaction readily suggest themselves as possibly applicable to such an object. The most essential processes of digestion are founded upon definite metamorphoses of this kind, which are confined to a suitable period of time. They present us with various circumstances of the several kinds of fermentation,—of the saccharine, the mucous, the lactic, and (less frequently) of the vinous and the acetous fermentations,—and with many stages of the putrefaction of azotized substances, for which chemistry has made out no sufficiently definite subdivisions.

418. The contactive operations (§ 299) which play so important a part in every series of the spontaneous decompositions of organic matter, obtain at almost every step of the chemical phenomena of digestion. Many of the substances admixed with the food—such as the mixture of saliva and mucus of the mouth, the gastric juice, the pancreatic fluid, and the several kinds of mucus furnished by the numerous segments of the intestine—contain ferments which, either alone or with the help of definite and accompanying substances, induce spontaneous decomposition of the solid alimentary matters.

419. In addition to this, there are other operations which exercise a manifold and important influence upon the whole process. Mastication reduces the food to a state of minute division, and mixes it with the fluids of the mouth. The peristaltic movement of the different subsequent sections of the digestive tube intimately mixes it with the solvent fluids at its disposal. But as these either possess mucous characters, or are directly mixed with quantities of mucus, nature in this way obtains a threefold advantage. Since the mucus diminishes the obstacle which friction offers, the solid substances glide more easily over the surface (§ 79). Besides this, it contains mucous corpuscles (Tab. II. Fig. XXXI, *c d*), which are variable microscopic constituents that plainly show it to be itself undergoing a metamorphosis, and hence to be peculiarly adapted to excite a contactive operation. Finally, its tenacity adapts it to retain fatty substances in the form of an emulsion, and to hold solid bodies suspended in a similar state of minute division. But since the surface of contact is thus increased (§ 31), the solvent juices subsequently poured out, or originally contained in the mucus, are enabled to act with greater efficacy. Finally, it is obvious that all these processes will be greatly furthered by the warmth of the internal organs.

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420. The different varieties of mucus which are furnished by the several segments of the alimentary canal,—the saliva, the pancreatic fluid, the gastric juice, and the bile,—all contain a large proportion of water. In addition to this, the gastric juice is slightly acid, and the saliva faintly alkaline. Hence compounds which do not resist dilute alkaline or acid solutions are at once taken up without further preparation. If, in spite of this, the assistance of drinks is required, the fact depends, not upon chemical, but solely on quantitative, relations. The absolute quantities of the digestive fluids are only too small, when large amounts of soluble alimentary compounds have to be overcome. But the study of absorption will teach us, that nature knows how to remedy this. Failing the necessary fluid appliances, large quantities of these soluble matters are not always rejected, but are mostly only more slowly taken up.

421. Sugar, salt, saltpetre, sulphate of soda, and sulphate of magnesia, are thus dissolved in the mouth. The acid gastric juice can drive off the carbonic acid of alkaline and earthy salts; and salt, or the alkaline phosphates which occur in most animal juices, will contribute, although only to a small extent, to the solution of the earthy phosphates.

422. The fluid of the mouth (Tab. II. Fig. xxxi), which we sometimes eject in the form of what is called spittle, consists in reality of a mixture of different secretions. It is probable that the mucous membrane of the mouth itself sets free certain solutions on its surface. The numerous excretory organs which it includes—such as the labial and buccal glands, or those of the gums, tongue, and palate, — yield a series of products which empty themselves into the cavity, and together form the mucus, of the mouth. The larger salivary glands situated in its neighbourhood, —*viz.* the parotid, submaxillary, and sublingual glands, and probably also those of the apex of the tongue — prepare the proper saliva, which is afterwards mixed with the mucus of the mouth. Under these circumstances it depends upon secondary causes, which of these constituents predominates in the mixture formed by the spittle.

423. The recollection or the sight of pleasant food, the acts of mastication, tobacco-smoking, titillation of the soft palate, speaking, and singing, all increase the quantity of the salivary fluids. And irritation of the gastric mucous membrane may lead to the same result. Frerichs [11]) found that, on introducing food into the stomach of a dog provided with a gastric fistula, more saliva was instantly secreted into the mouth. And if salt was substituted for food, the quantity was still greater. This explains how a morbid irritation of the gastric membrane may produce an energetic conflux of the salivary fluids.

424. When large quantities of saliva are required for chemical or physiological observations, various artificial means are made use of. Tobacco-smoking, and, especially, irritation of the soft palate, are very

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useful in this respect. But such an experiment furnishes a mixture which is in all probability more diluted than usual.

425. Such observations teach us, that the salivary fluid, after the removal by filtration of the mucus and epithelium which is mixed with it, is one of the most aqueous fluids of the body. For instance, my saliva leaves only ·77 per cent of solid residue. And in eighteen special analyses Frerichs obtained extremes of ·51 to 1·05, with an average of ·72 per cent.

426. The act of mastication, which minutely divides the food so as to produce a number of interstices, also causes it to be moistened with considerable quantities of the salivary fluid. We might hence expect, *à priori*, that the amount of fluid taken up would generally vary with the dryness and the capacity for minute division possessed by the food. A series of experiments undertaken by Lassaigne confirms this presumption. The increase of weight after complete mastication amounted to only 4 per cent for apples, 8 per cent for nuts, 28 for biscuits, 43 to 45 for beef, and from 30 to 127 for the different kinds of bread.

427. Since the healthy saliva which is poured forth in large quantity during mastication has an alkaline reaction, all those constituents of the food which are soluble in a weak alkaline solution are instantly dissolved, as far as their quantitative proportions will allow. The mucous quality of the fluids of the mouth may contribute to smoothen the alimentary bolus. And as this is afterwards pressed through the isthmus of the fauces, it scrapes off mucus from the root of the tongue, the soft palate, and the tonsils (§ 377), so as to envelope itself with a slippery covering, which allows it to glide onwards so much the more easily.

428. The salivary fluids are incapable of dissolving fats or coagulated albumen. Hence portions of meat which remain in the interstices of the teeth are only softened and decolorized by even a long sojourn. But under favourable circumstances of temperature, the saliva possesses the property of converting paste into dextrin and grape sugar, and in this way renders it soluble. Higher degrees of temperature accelerate this metamorphosis in an extraordinary manner. But the temperature of 96·8 to 98·6°, which is possessed by the completely masticated food, is quite incapable of at once inducing this change. Hence the saccharine fermentation of boiled starch is never completed at the time the bolus descends into the pharynx and œsophagus.

In spite of this, however, the admixture of saliva is by no means useless, but forms, to a certain extent, a provision for the future. We shall see that the presence of the gastric juice does not arrest this action of the saliva. Hence it proceeds in the stomach, where the food remains for a considerable time.

429. Many ruminants which secrete much saliva introduce large quantities of it into their first two stomachs, and especially into the

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paunch. This phenomenon has an obvious relation to the influence exerted by saliva upon starch which has been boiled or broken up by the action of warm water.

430. Raw starch also may certainly succumb to the power of the saliva. But it opposes a much greater obstacle. If slices of raw potatoes are mixed with the salivary fluids, and exposed to a temperature of 104° during twenty-four hours, it will often be found that most, if not all of them, have retained their form, and become blue with tincture of iodine. And an examination of the contents found in the first stomach of ruminants under high magnifying powers not unfrequently affords similar results. According to J. Vogel, some of the matters vomited by the human subject teach the same fact. And we shall also find, that on the other side of the stomach nature has applied digestive juices which are also intended for the metamorphosis of starch. The swallowed saliva only forms a kind of substitute for the stomach, whose gastric juice is exclusively occupied with the solution of other constituents of the food.

431. The fluids of the mouth, as they are generally evacuated,—forming a mixture of the secretions of its mucous membrane, the glands contained in it, and the pure saliva,—are at all events capable of inducing a most energetic saccharine fermentation in boiled starch. Many observers,—such as Bidder, Jacubowitsch, and Schmidt,—altogether deny this capacity to the pure saliva and the pure salivary fluid of the mouth. While others,—as Lassaigne, Magendie, Rayer, Bernard and Barreswill,—ascribe it to the latter of these two fluids only. Finally, it was found by Frerichs that the watery extract of the proper salivary glands, or that of the mucous membrane of the mouth, only furnished traces of sugar; while a mixture of the two gave much more considerable quantities. Mialhe named the substance precipitable by alcohol diastase, because it had the power of inducing the saccharine fermentation of starch, just like the vegetable diastase (§ 299). But hitherto it has been found impossible to exhibit this agent of the metamorphosis in a pure state. Besides, the power of inducing saccharine fermentation also belongs to many kinds of mucus, to blood in which putrefaction has commenced, to the hepatic or renal substance, and probably to numerous other structures of the body when not quite fresh.

432. The short time during which the mucous and slippery alimentary bolus remains in the œsophagus allows of no very important chemical changes. But at present we are ignorant whether the glands of this part of the alimentary canal furnish a mixture which is capable of continuing its operation in the stomach.

433. The greater part of the internal coat of the stomach consists of the vertical gastric glands (Fig. 78 and Tab. IV. Fig. LIII.); clusters of which may easily be recognized by a low magnifying power in proper

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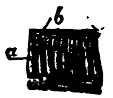
sections of the mucous membrane. They furnish the gastric juice, which is a mixture of a tenacious fluid with granules, nuclei, and pavement-cells. These denser corpuscles of different kinds probably form the visible expression of that continual metamorphosis, that perpetual change, which the whole is undergoing, and on which the solvent powers of the gastric juice, and the qualities ascribed to the pepsin or theoretical digestive substance, may be supposed to depend. But since the secretions of many other small glands which exhibit similar microscopic constituents are devoid of similar properties, it follows that the characteristics recognizable in this mixture by the eye will not suffice to explain its intimate constitution.

Fig. 78.



434. The empty stomach contains a mucus which has a neutral or faintly acid reaction. If this be scraped off, we come upon a fluid below it which strongly reddens vegetable colours. If the exposed gastric mucous membrane be titillated, or if stones and other insoluble substances be introduced into the uninjured stomach of a living dog, there exsudes a more considerable quantity of a decidedly acid secretion. The food acts in a similar way. Its mere consistence forms, as it were, a stimulus, which educes the acid gastric juice necessary to its elaboration.

435. We have seen (§ 420) that the fluids of the mouth which descend with the food have an alkaline reaction; and we shall find that the blood, the lymph, and many mixtures which are added to the chyme in the subsequent parts of the alimentary tube, usually exhibit the same quality. Since, notwithstanding this, the gastric juice always exhibits a free acid, there must be something in the walls of the gastric glands, or in the metamorphosis excited in their interior, to which this strong acid reaction is due. According to Bernard, if warm blood be injected into the arteries of the stomach of a newly killed animal, an acid gastric juice immediately exsudes.

436. The cause on which the free acid depends has been much contested. At present we know that hydrochloric acid is not, as was supposed, the basis of the phenomenon; and that the gastric juice of granivorous birds which swallow flint-stones, does not contain any free hydrofluoric acid. The acid is most probably the lactic. But it may not only be furnished by the stomach, but also from the spontaneous decomposition of the hydrates of carbon, from altered milk, or from other substances. Butyric and other volatile fatty acids, or acetic acid, are also exceptionally met with in the replete stomach. But chemistry has hitherto been unable to decide whether the acid reaction depends on free acids, acid salts, or acid organic compounds.

437. We shall soon see that the most important operations of stomach digestion may be imitated by mixing the watery extract of the gastric mucous membrane with small quantities of acid, so as to form an arti-

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ficial digestive fluid. Various acids may be used with effect, so long as they are present in corresponding minimal quantities. But the necessary quantities of acid, and the rapidity of the operation, vary with the different fluid which is applied. Hence the question, which is the active acid of the gastric juice, is so far of importance, as that it is an inquiry into the acid compound which nature originally makes use of, and which will probably correspond to the most suitable collateral conditions.

438. The gastric juice is not intended for the transformation of the hydrates of carbon or the fats. These continue to be attacked by the admixed saliva, since its influence is not annihilated by the acid gastric juice. It may also happen that fatty acids are produced. But the chief object of gastric digestion is the solution of coagulated albuminous substances.

439. If the stomach of a newly killed animal be filled with water and allowed to stand twenty-four hours, and if the fluid be then filtered and concentrated at a moderate heat, we obtain a mixture which, by a proper addition of acid, forms a tolerable artificial digestive fluid. Small portions of gastric mucous membrane may also be directly mixed with faintly acidulated water. And a stomach which has been rapidly dried and kept for years serves almost as well as a fresh one. Many experimenters extract the gastric mucous membrane with water, evaporate the filtered fluid, and either treat it at once with alcohol, or only after precipitation with acetate of lead and separation of the precipitate from the metal with the aid of sulphuretted hydrogen.

440. It is obvious that, supposing nature to require a free acid, this will only be made use of in a very dilute state, since otherwise the tissues themselves would be attacked. Experiments on artificial digestion also teach us that it is only very small quantities which lead to the desired end; such "microlytic" quantities of hydrochloric acid, for instance, as either cause but a faint precipitate in a watery solution of albumen, or do not affect it at all. The more energetic action of larger quantities injures or disturbs the results.

441. The favourable influence of moderate degrees of heat, small quantities of acid, and proper fermentative substances, may be easily verified in every kind of artificial digestive fluid. If we imitate the gastric temperature of the warm-blooded animals by a constant heat of 96·8° to 105°, the solution occurs much more rapidly than at from 59° to 68°. A boiling heat annihilates the digestive power of the fluid. And all temperatures above 122° remarkably injure it.

442. If the non-acidulated gastric juice be allowed to remain at a temperature of 96·8° to 105°, it soon developes an intense putrefactive smell. And albuminous bodies added to it are not immediately dissolved, but are at most only conducted to a partial and ineffective spontaneous decomposition. But if a small quantity of acid be present, this putrefaction

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does not appear. The whole takes the acid smell of matters vomited, retains it for a very long time, and effects a genuine solution of coagulated albuminous substances.

443. Very dilute mineral acids are certainly capable of slowly dissolving small pieces of meat or albumen. But even an imperfect effect of this kind demands many days and a high temperature. We see from this what advantages nature obtains by combining moderate heat, slight acidulation, and a suitable ferment.

444. Although artificial digestion repeats the most essential operations of the gastric juice of the living stomach, yet the two exhibit many important differences. If the mucous membrane of the stomach be extracted with water, foreign compounds,—such as soluble albumen,—may be taken up from the tissues themselves. Hence this digestive fluid offers reactions, which are not only different from those of the gastric juice itself, but are in some respects more variable. If small pieces of stomach be digested in acidulated water, they as it were consume themselves. Their fibrous substances are gradually liquefied, and we finally obtain a thick mixture, from which the large portions of gastric mucous membrane formerly present are generally absent. Something similar may occur to a partial extent in the dead body. Many cases of apparent gelatinous softening met with in the dead stomach depend upon the fact, that the strongly acid gastric juice has attacked the neighbouring tissues after death. But it is obvious that in the living animal, this casual effect is either wanting, or is rendered harmless by a compensative development.

445. Setting aside these differences, the changes which we meet with are tolerably uniform, whether we follow them in an artificial digestive fluid, or in a living stomach. In the latter, we have two ways of accomplishing our object,—the examination of matters vomited, or the institution of gastric fistulæ.

446. Beginning with the albuminous substances, we shall again find that much depends upon their state of aggregation and their other qualities. The fibrine of blood offers less resistance than the albumen of hard-boiled eggs. The muscular fibres are more easily overcome than the denser fibrous masses of tendons or ligaments; and hard cheese succumbs so slowly, that a part of it often passes on to the duodenum.

447. Sharply-cut dice of albumen first become more transparent at their corners, while a less transparent nucleus remains in their middle. The effect thus proceeds from without inwards, just as in every other solution. The corners are rounded off, softened, and finally altogether dissolved. The nucleus undergoes similar changes. And finally, we have a greyish-white and cloudy mass, in which a greater part, if not all, of the albumen is not merely mechanically subdivided, but chemically taken up.

448. Flesh at first behaves just as it would in any other faintly acidu-

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lated fluid. The areolar tissue which is interposed between the muscular fibres, and the substance of these structures themselves, become more gelatinous and transparent. The sarcolemma (Tab. IV. Fig. LIV. *b*) and its nuclei (*c*) are more easily distinguished. Later, these structures disappear. But the transverse striæ of the muscular fibres may be long recognized, especially under the influence of shadow. The mass of fibres is then separated into fragments, such as are represented in Fig. 79; and we finally get a thick and imperfect solution of the whole. According to Frerichs, the thicker muscles of the adult resist longer than the smaller ones of the young animal. Other circumstances being equal, boiling or moderate roasting furthers the rapidity of the solution.

FIG. 79.

449. Casein may demand the digestive action of the stomach under two different forms. We often introduce it as a solid in cheese. And under the influence of the gastric mucous membrane, milk soon coagulates, so that the precipitated casein requires a new dissolution.

450. Cheese belongs to that class of albuminous compounds which are overcome by the digestive fluid, although able to offer it a considerable resistance. Hence relics of it not infrequently pass into the duodenum.

451. Very small portions of gastric mucous membrane, or of the acidulated artificial digestive fluid, precipitate considerable quantities of casein from milk. This effect probably depends, not so much upon the immediate neutralization of the alkali of the milk, as upon a special contactive agency. According to Mitscherlich, the quantities of lactic acid produced from the sugar of milk at first bear no proportion to the amount of precipitated casein. The albuminous wall which surrounds every milk-corpuscle (Fig. LXXX. *a*) is not unfrequently dissolved, so that the globules of oil or butter become free, and subsequently run together into large drops by their accidental contact. The other fluids are for the most part absorbed in the stomach. The casein which remains, and the fatty deposit, diminish under the influence of the digestive action, until finally the residue passes on into the duodenum.

452. Vegetable albumen, legumin, and gluten are dissolved in the stomach like the animal albuminous substances. Gelatin is also overcome. But just as the albumen dissolved in an acidulated artificial digestive fluid is not precipitated by a boiling heat, so the solution of gelatin has altogether lost the power of coagulating on cooling. Softer tissues which yield gelatin, such as the different kinds of cellular tissue, easily succumb to the influence of gastric digestion. Denser ones, on the contrary, such as tendons, ligaments, or elastic fibres, often resist the most continuous action. In thin laminæ of cartilage the intercellular substance (Tab. III.

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Fig. XLV. *a*) is first attacked. Their dissolution is on the whole slow; but they finally disappear to the extent of the greater part of their nuclear structure. The bones only lose a part of the large quantity of calcareous salts which they contain. But their cartilage yields more quickly to the gastric juice. It appears to behave like the substance of the permanent cartilages.

453. We know that other circumstances being equal, a powder is more quickly dissolved than a larger solid body, since the subdivision into small masses increases the surface of mutual contact (§ 31). The like is found to obtain in gastric digestion. The same quantity of coagulated albumen is liquefied far sooner when cut up into a great number of thin slices than when exposed in the form of a single large cube. Hence the thorough mastication of the food not only subserves the use of mixing it more intimately and copiously with the fluids of the mouth, but also assists to accelerate the subsequent gastric digestion.

454. The movements of the stomach also afford important advantages. They knead up the most superficial layers with the gastric juice, and finally move them onwards so as to allow of a repetition of the process with deeper ones. And since the more dilute and completely fluid substances are immediately absorbed by the stomach, those denser ones alone remain which yet require the action of the gastric juice, just as a precipitate which we seek to separate by filtration is left more accessible to subsequent extraction. The withdrawal of the fluids has also the advantage of preventing that disturbing influence which would result from too great a dilution.

455. The quality of the chyme which passes immediately into the duodenum must evidently vary with the different nature of the food. It generally constitutes a mechanical mixture of a grey gelatinous semi-transparent mass with all those relics that are capable of resisting the gastric digestion. The former constituent contains those dissolved substances which circumstances will no longer permit to be received into the lymph or the blood. Hence we may recognise in it relics of gum, sugar, lactic acid, and pectin, after the use of potatoes, bread, or other vegetable food; or of albuminous and gelatinous bodies after a corresponding animal diet. The mechanical admixture may consist of raw starch granules; decolorized simple, dense, or woody cells, and bundles of vessels; fat; pulverulent relics of hard albumen or casein; fragments of cartilages; muscular fibres; tendons; ligaments; splinters of bone; or salts of the osseous tissue. The fluid substances, which are chiefly absorbed, but partially conveyed into the duodenum, seem always to include considerable quantities of ashes. Herbivora furnish, on an average, more than carnivora.

456. We have already seen that a great influence is exercised by the state of aggregation of the food. Hence the digestibility of particular alimentary substances must not be decided from their chemical characters

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only. An additional reason for this caution is found in the possible state of the gastric mucous membrane itself. The intensity with which it is aroused from its state of rest immediately depends upon the moderate degree of friction exerted by the matters that are introduced into the stomach. Small quantities of cold fluids favour the secretion, while it visibly suffers under the influence of larger masses of ice. Blondlot and Bernard [12]) believe themselves to have found that the application of a weak solution of carbonate of potash furthers the solution of meat more energetically than that of a little wine-vinegar; and hence that the faintly alkaline character of the saliva, and of many kinds of food, such as albumen, assists the gastric function. But on the other hand, larger quantities of alkali are injurious. Large quantities of salt limit the artificial digestion of coagulated albuminous substances. It is hence self-evident that not only the nature, but also the mixture, of the aliments has a decided influence. The mucous membrane of the stomach appears to be itself one of the most sensitive parts of the body. Violent febrile excitements, or the direct application of strong mechanical or chemical irritations, easily alter the secretion which it furnishes, and the movements which it takes on. We thus get a gastric juice which either digests badly or not at all: and unusual phenomena of fermentation appear. Bile regurgitates into the stomach; and nausea or vomiting frequently accompany these irregularities.

457. That residue of the food which passes into the small intestines next encounters the intestinal juices; that is, the different secretions which are furnished by the glands of Brunner, Lieberkuehn, and Peyer, and probably also by the mucous membrane itself. In the descending portion of the duodenum they also meet with the pancreatic fluid and the bile.

458. Since we cannot completely separate the secretions of these small intestinal glands from the other admixtures, it is impossible to decide what functional differences correspond to the structural peculiarities of these secretory organs. According to Middeldorpf [13]) the fluid of the glands of Brunner, which are more developed in herbivora, is incapable of dissolving pieces of flesh or albumen, while it is able to convert starch into grape sugar.

459. Many collateral circumstances may essentially alter the reactions of the mucous substances present in the intestines. In testing the upper segments it is possible that the acid chyme which has entered conceals the alkaline character of the secretions. The production of lactic acid from the hydrates of carbon taken in the food may induce similar errors. If we add to this, that small quantities of fluids having a weak reaction may be very faintly or even incorrectly indicated by the vegetable colours usually employed, we shall not be surprised at the contradictions which have resulted from such examinations.

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For instance, Middeldorpf found that the secretion from the Brunnerian glands of the pig had an acid reaction; while on the other hand Frerichs found both it and that of the follicles of Lieberkuehn to be alkaline. It must however be admitted, that the originally alkaline quality of the intestinal juice becomes more decided the further we descend from the duodenum.

460. The mucous juice of the intestines assists the residuum of the food in gliding onwards. Its tenacity causes the more fluid fats to be minutely subdivided in the form of an emulsion, and allows them to retain this condition. It can also convert starch into sugar, although not very energetically. And since the mucus includes substances which are undergoing metamorphosis, it is possible that under favourable circumstances it may furnish an organic ferment. It must however be remarked, that the intestinal mucous membrane, when mixed with faintly acidulated water, is generally unable to dissolve coagulated protein-compounds.

461. The pancreatic fluid of healthy animals appears to be poured out in considerable quantity during the time of digestion only. Its characters seem to be very easily altered by abnormal circumstances. Leuret and Lassaigne, Tiedemann and Gmelin, Bernard, and Frerichs, inserted a tube into the pancreatic duct of living animals and birds, either from the duodenal orifice of this canal, or in some part of its course. But the fluids thus obtained differed essentially from each other: for certain of these observers found considerable quantities of albumen, while others did not. On the other hand, almost all remarked an alkaline character of the pancreatic fluid so obtained. But the watery extract of the fresh pancreas of the cow has sometimes an acid reaction.

462. The pancreatic fluid must contain certain substances which have a tendency to decomposition. If the pancreas be triturated with water, or extracted as completely as possible, the whole putrefies within a short time at the blood-heat. This phenomenon furnishes an indication of the reason why the pancreatic fluid so powerfully excites fermentation.

463. If the pancreatic mass be triturated with water and mixed with paste, the latter is quickly dissolved, and is converted into grape-sugar. If the whole be allowed to remain at a proper temperature, fermentation soon goes further. A strongly acid reaction may be remarked, and may be conjectured to depend upon lactic acid. While an energetic development of gas seems to indicate a copious production of carbonic acid.

464. An acid character of the fluid,—or the presence of bile, intestinal mucus, or pieces of small intestine,—does not suspend the powerful fermentative influence of the artificial pancreatic fluid. We may thence conclude, that this influence obtains during life, and greatly contributes to the production of lactic, and even of carbonic, acid from the suitable hydrates of carbon. But granules of raw starch are much more slowly overcome

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than a mass of paste. Thus if a large quantity of the former be mixed with pancreatic fluid, and allowed to remain for three days at blood-heat, the greater part of the starch granules are found unchanged. The whole may have an offensive acid smell, although only small quantities have been dissolved. This explains why many starch granules are not elaborated in the upper part of the small intestine, but are carried on further intact.

465. The pancreatic fluid certainly contributes to the minute division of fluid fat in the form of an emulsion. But this effect, which also belongs to other digestive juices, probably constitutes no essential element of its function.

466. Nor is the necessity of this secretion sufficiently explained by the energetic fermentation which it excites in paste. And since it does not dissolve pieces of albumen, it remains for further investigations to show what finer changes may be produced in the azotized alimentary substances under the influence of the pancreatic juice. It appears to facilitate the deposit of resinous substances from the bile.

467. The numerous attempts of chemists to investigate the constituents of the bile have not hitherto led to any satisfactory physiological results. The ease with which this mixture is decomposed causes the simplest chemical processes to furnish products of metamorphosis which are not unfrequently viewed as its essential constituents. And although it is probable that the bile undergoes some alteration in the intestine, and even in the gall-bladder itself, still it has hitherto been impossible to exhibit with sufficient clearness the course of the changes which obtain in these situations.

468. We shall hereafter see that the bile separates from the blood certain substances previously useless. A part of these substances is gradually rendered insoluble and discharged in the excrements. But those compounds which retain their liquid form, and perhaps many which are gradually redissolved, are returned anew into the blood. That constant arrangement in the animal kingdom, by means of which the bile is poured out into the commencement of the small intestine, admits of a double interpretation. Since this secretion must accompany the relics of the food for a great part of their course, it may be intended to afford some essential assistance to digestion. But it is also possible that the co-operation of the small and large intestines is required in order to separate the bile into constituents which are soluble and susceptible of absorption, and into others which are denser and destined to expulsion. The changes which it provokes in the residue of the food would thus be mere secondary phenomena, having a more or less subordinate import.

469. The experiments hitherto made are incapable of deciding between these two views. Since digestion does not completely cease in cases of jaundice or of artificial biliary fistula, it follows that the bile is not

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indispensable to the general process. But the physical properties of the excrements suffice to show that this fluid is to a certain extent a regulator,—and perhaps a definite and not unimportant condition—of that peculiar spontaneous decomposition which the relics of the food undergo. But much of this is very indefinite, since chemistry has scarcely penetrated these peculiar phenomena of putrefaction.

470. Since fresh bile is by no means strongly alkaline, but is usually either neutral, or at most, but faintly alkalescent, the view which was formerly so frequently propounded,—that it was intended to neutralize the acid chyme,—is at once negatived. Even when the contents of the upper part of the small intestine have taken up a large quantity of bile, they generally preserve their acid character. On the other hand, however, the free acid reacts on the bile. The colours of the substances present in the intestine are tolerably explained by this fact.

471. If the intestinal contents be followed along the small and large intestines they will be generally found to become first yellowish or yellowish-green, then green, and finally brown. Separate brown microscopic masses appear before this colour is present to the naked eye. If bile be treated with small quantities of acid, or with an acidulated digestive fluid, yellowish-green or green precipitates may be artificially produced. The unacidulated gastric mucus, salt, or muriate of ammonia, do not give rise to this change. One may thence conclude, that it is caused by the biliary precipitate which is produced by the acid contents of the upper part of the small intestine. The precipitate consists chiefly of cystic mucus, of cholepyrrhin or biliary colouring matter, and of fatty bodies: and it probably contains other constituents of the bile.

472. As the bile gradually descends along the course of the intestinal canal, it slowly undergoes important changes. It is probable that the fluid which remains after the separation of the solid precipitate is gradually absorbed. And on an average, the lower the residuum of the food has descended, the less the quantity of bile which can be extracted from it by water. We here meet with biliary compounds which are only soluble with difficulty; such as, for instance, the supposed modifications of cholepyrrhin,—taurin, dyslysin, and the like. But it is at present impossible to specify the details of this metamorphosis with sufficient accuracy. We only know that these combinations usually leave the body with the fæces.

473. By drying the precipitate which is thrown down from putrefying human bile we get a brown substance which diffuses the strongest smell of human ordure, especially after the application of a small quantity of water. The same results may be obtained with the semifluid contents of the cæcum. If the experiment be repeated with ox-bile, we obtain a yellowish-green substance which smells like cowdung.

474. Many combinations which are produced by the artificial treat-

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ment or the putrefactive decomposition of albuminous substances have also a more or less distinct odour of fæces. But we should be wrong if we therefore attributed the smell of the excrements to the food. For when these putrefy alone, this smell is generally absent. And if the entry of the bile is prevented in jaundice, the greyish-white and clayey fæces have a smell which is intensely putrefactive, but quite different from that of healthy excrements. And of many animals supplied with the same food, each will furnish its peculiar fæcal odour,—an odour which sometimes recurs in a weaker degree in the blood, the urine, and the cutaneous evaporation. It therefore follows that the two most prominent physical qualities of the excrements—the colour and the smell—chiefly depend upon the bile.

475. Hitherto the bile has not been shown to possess any peculiar solvent powers. Morsels of albumen or cheese, and more or less dense masses of fibrine, resist its influence with great obstinacy. Just as little does it possess the power of converting starch into grape-sugar with any considerable force; or of inducing the lactic or acetic fermentation. In one word, in the present state of our knowledge it may be regarded as a mixture which is incapable of affording any direct support to the influence of either the gastric juice, the intestinal mucus, or the pancreatic fluid.

476. Comparative researches rather lead to the conviction, that the bile leaves intact many of the phenomena of metamorphosis which appear in the intestinal canal, while there are others which it has the power of limiting. Hence it seems to be serviceable by its negative, rather than by its positive, action.

477. The pancreatic fluid operates as a powerful excitant of decomposition, whether bile be present or not. If large quantities of bile be mixed with the artificial acidulated digestive fluid, the latter loses the capacity of dissolving morsels of albumen. Having mixed acidulated water with pieces of the mucous membrane of the human cæcum, and with bile, I found that its action upon beef was weaker than usual. The addition of the biliary precipitate obtained by acetic acid seemed to delay solution more than an admixture of pure unfiltered human bile. The penetrating putrefactive smell offered by the fæces of jaundiced subjects had long led to the conclusion that the bile was opposed to putrefaction or had an antiseptic agency. And Frerichs found that after deligation of the biliary duct, the filtered albuminous contents of the intestine were made rose-coloured by nitric, and violet by hydrochloric acid. This reaction,—which has also been observed in the alvine evacuations of persons suffering from cholera and nervous fevers,—indicates a substance evolved by the putrefaction of albuminous matters.

478. We may hence conceive that the bile sets definite limits to the decomposition of many albuminous substances; while it does not hinder the metamorphoses which are induced by the pancreatic fluid, and pro-

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bably by the intestinal mucus. It certainly possesses antiseptic properties, but only for certain stages and kinds of spontaneous decomposition. It is probable that an extension of our knowledge of the putrefactive process would allow a more accurate estimate of the agency of the bile.

479. The colours of the excrements show that the biliary constituents which are expelled from the rectum only attain their perfect and normal metamorphosis after the alimentary residuum has remained a certain time in the intestinal canal. The yellow evacuations of diarrhœa contain a certain quantity of pure bile. And since the excrements of the sucking child are green or yellowish-green, and fluid,—while those of the older infant are yellow, more solid, and finally brown,—we may conjecture that the character of the bile, or the mode of its decomposition, or both of these circumstances, vary with the age.

480. We shall subsequently see that the greater part of the fluid fat is converted into chyle in the course of the small intestine. The movement of the intestine intimately kneads it up with the mixture of intestinal juices, pancreatic fluid, and bile. It then forms very minute and finely-divided drops. Possibly a very small quantity is converted into fatty acids. But, as above mentioned, these may proceed from the hydrates of carbon: and the greater part of it certainly remains unchanged.

481. Hitherto we know extremely little of that series of changes which accompanies digestion, and the formation of fæces, in the large intestine. The cause of this lies not so much in the physiological as in the chemical circumstances. The chemistry of the present day furnishes no sufficiently clear insight into those limited phenomena of putrefaction which appear in the course of the large intestine.

482. Confining our attention to the outward appearance,—the semifluid contents of the cæcum have a consistence which tolerably corresponds to that of the contents of the lower part of the small intestine. While in the course of the colon we find denser excrementitious substances; which, however, always contain 3-4ths of their weight of water and other volatile matters. The combinations destined for expulsion are condensed in the large intestine of man and certain of the mammalia,—as, for instance, the rabbit, the sheep, and the horse.

483. Although the contents of the cæcum not unfrequently offer a distinctly fæcal smell, yet in the remaining course of the large intestine, this odour is remarkably increased. The human excrements only acquire a brown colour by degrees. If we also consider, that compounds of hydrogen,—such as carburetted and sulphuretted hydrogen,—constantly appear in the large intestine, and that ammonia is more abundantly present (in the form of its double salt, the ammoniaco-phosphate of magnesia), we can scarcely doubt that the residue of the food and of the biliary precipitates is subjected to a limited process of putrefaction, such as that which occurs spontaneously under water.

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484. While the purely carnivorous animals possess a very small cæcum, in the herbivora it attains a considerable size. In the rabbit and hare the great sac it forms is generally distended by an alimentary residuum. Those raw vegetable substances which require a longer elaboration, and therefore a longer delay, in the alimentary canal, probably find in the cæcum their most favourable digestive receptacle.

485. The chief agents of the metamorphosis of the hydrates of carbon, are the saliva, and the secretions poured into the small intestine; while that of the less soluble albuminous and other azotized substances, is effected by the gastric juice. The fluid fats are mostly absorbed in the small intestine. And the addition of a special digestive system in the large intestine can only have the object of making useful that which has escaped the previous portions of the canal. So that the cæcum and colon form, as it were, the second frontier guard, by means of which the alimentary residuum is subjected to an additional examination, in order that as little useful matter as possible may be lost.

486. A collateral circumstance probably favours this repeated extraction. The azotized substances which the gastric juice has not overcome immediately pass through the small intestine. They are here mixed with fermenting matters, which have the power of unloosing them, or unlocking their molecules to a certain extent. They are thus more easily dissolved in the large intestine. And if we remember that many nutritious vegetable substances are enclosed in coverings of cellulose, we may readily imagine that the metamorphoses which occur in the small intestine will considerably facilitate their being subsequently overcome. And even where the walls of the cells are not dissolved, they may acquire a considerable increase in permeability and diffusive capacity.

487. At present we do not know of any definite and special use which is subserved by the probably essentially alkaline secretion of the cæcum. If this intestine contains hydrates of carbon, they frequently undergo the lactic fermentation. The lactic acid thus produced might offer two collateral advantages. It would independently dissolve many compounds,—especially those of vegetable food,—and salts, such as the carbonate of lime and magnesia. And in conjunction with the organic matters of the cæcal secretion, it would furnish a mixture capable of overcoming coagulated albumen. I have found that a mixture of acidulated water with pieces of the mucous membrane of the cæcum has a weaker and slower action than a digestive fluid prepared from the gastric membrane; but that the final results prove the solvent power to exist.

488. It is probable that the alkaline secretion of the large intestine can also assist in taking up albuminous substances. The filtered contents of the colon frequently contain albumen. The residuum of vegetable food here continues its fermentation, so that not only lactic, but butyric, acid may appear.

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489. The excrements contain constituents of three kinds,—the unelaborated solid parts of the food, the insoluble or difficultly-soluble cellular deposits, and mucus or other organic combinations which are evacuated *per anum*. The hybernating animals show that the absence of food does not suspend the formation of excrement. For instance, we shall hereafter see that a hedgehog which has taken no food during some months of its winter sleep, from time to time evacuates considerable quantities of solid or semi-solid fæces.

490. The densely ligneous vegetable tissues which are introduced in large quantity with the food, are either expelled unchanged from the anus, or are decolorized and partially extracted. In this way the horse gets rid of a large quantity of the vegetable stalks which it has eaten. The human fæces sometimes contain hard envelopes of seeds, and cherry or plum-stones. And even when a more common and apparently more wholesome food is made use of, the fæces still generally contain microscopic relics which are exactly similar to others that have been overcome by the digestive fluids.

For example, Tab. I. Fig. XVII. exhibits the constituents of healthy human excrements diluted with water. Here *a* is a starch granule, the surface of which being in focus allows its concentric laminæ to be visible; *b c* are other starch granules, which lie more deeply, and hence look almost like drops of oil. At *d e f* are lignified epidermoid cells, and reticular vessels of the vegetable food. At *g* is seen a muscular fibre from the meat which has been eaten, and which has only become clear and colourless: *h* is another fibre which has broken down into transverse fragments. Crystals of ammoniaco-phosphate of magnesia are shown at *i k l*, *m* represents epithelial scales from the neighbourhood of the anus, *n* biliary masses, and *o* numerous small molecules.

491. Hitherto we have no large and complete series of analyses of the excrements. Berzelius, who examined the fæces of a labourer fed upon bread and mixed food, found 75 per cent of water, ·9 of bile, ·9 of albumen, 2·7 of extractive matters, 1·2 of salts, 7 of insoluble remains of the food, and 14· of mucus, biliary resin, fat, and other animal compounds. The elementary composition of the excrements will again occupy our attention in the chemical phenomena of nutrition.

492. The spontaneous decomposition undergone by the food in the alimentary canal evidences itself by two supplemental occurrences; by a change in the nature of the gases contained in the intestine, and by the occasional formation of mould.

493. The frothy saliva contains a certain quantity of air in mechanical union; and not unfrequently peculiar movements of deglutition introduce larger quantities into the stomach. But the gases contained in this organ do not possess the composition of pure atmospheric air. They contain more carbonic acid, less oxygen, somewhat less nitrogen, and in

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rare instances, small quantities of hydrogen. The cause of this phenomenon is twofold. We shall hereafter see that the mediate contact of the atmosphere with the blood causes oxygen to be given off, and carbonic acid to be taken up. Carbonic acid and hydrogen may be set free by the fluids which are drunk, by that fermentation of the hydrates of carbon which is induced in the stomach itself, and especially, by the production of butyric acid. That solution of the dense albuminous substances which is effected by the gastric juice furnishes no gaseous substances. Nor does it require the presence of atmospheric air, although this is indispensable to many forms of fermentation.

494. The small intestine contains considerably more carbonic acid, less nitrogen, little or no oxygen, and considerable quantities of hydrogen. The progress of fermentation in the hydrates of carbon sufficiently explains this mixture.

495. A more or less considerable content of carburetted hydrogen distinguishes the air contained in the large from that in the small intestine. Sulphuretted hydrogen, and the odorous matter of the excrements, are usually present in flatus. The presence of carburetted hydrogen points to the fact that the quantity of free oxygen is insufficient to convert all the carbon into carbonic acid, and that a certain quantity of water or some other hydrogenous substance must be decomposed, in order to the conversion of part of the carbon into a gaseous compound. The ammonia which is set free from the decomposition of azotized bodies, and which may also be developed from the changed bile, appears to be chiefly combined with other substances,—and especially with sulphate of magnesia.

496. Fermenting mixtures which have a free acid reaction greatly favour the multiplication of the various kinds of mould. Hence we frequently meet with them in the course of the alimentary canal. The acid gastric juice can first allow of their development. The acid fermentation of the hydrates of carbon, or a morbid production of acid, also frequently form favouring circumstances. Infusoria appear on the whole with less frequency.

The tartar or mucous earthy mass which frequently covers the under part of the crown of the teeth contains peculiar articulated threads which probably belong to the vegetable kingdom, and moveable creatures resembling vibriones. Vomiting not unfrequently furnishes those peculiar vegetable parasites which have been named the sarcina ventriculi (Tab. II. Fig. XVIII.). The yeast plant (Tab. II. Fig. XIX.), some species of hygrocrocis, and other thready fungi, may be met with in all parts of the alimentary canal, especially in herbivorous animals.

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CHAPTER VII.

ABSORPTION.

497. The porous structure of the animal tissues leads to numerous and mutual actions between the juices of the body and the fluids which come into contact with its organs. Special means for favouring these actions allow of foreign solutions being taken up in large quantity,—or, as it is usually expressed, *absorbed*. That solution of solid bodies, which is necessary to diffusion, may be effected by the organic mixtures themselves. The transit these induce is sometimes distinguished by the term *resorption*.

498. All phenomena of this kind conduct into the blood the combinations which are exposed to them. Solutions first gain the nutritive fluid which soaks the tissues. They can thence pass immediately into the mass of the blood. But certain collateral objects often require that they should previously enter the lymph, and flow onward with this liquid in the absorbents or lymphatics, so as to be only mixed with the blood at a later period. Hence we must distinguish as much as possible between the immediate and the mediate transit into the blood; or between the entry into the blood and into the lymph.

499. The alimentary substances liquefied by digestion form an important source of the phenomena of absorption. The lymphatics of the alimentary canal often specially take up the fatty matters contained in the food. Since the oil-drops in the lymph are minutely divided as in an emulsion, so as to give this fluid a milky appearance, the lymph thus altered during the digestive act is named the chyle; and the lymphatics which pass from the intestinal canal, and especially from the small intestine, are called the lacteal or chyliferous vessels. But this time-honoured distinction is based upon outward and collateral circumstances only. The lymphatics of the small intestine only enjoy more frequent opportunities than others for taking up fatty matters. Hence during fasting, their contents correspond with ordinary lymph. And if other lymphatics absorb fat, they also contain chyle. This may be seen, for instance, in the lymphatics of the large intestine, if a meat-broth which is rich in fatty matter be introduced *per anum*.

500. Since absorption depends upon the porosity of the walls of the vessels which limit the blood and the lymph, it would seem to be possible that not only chemical solutions, but solid bodies of very small size,

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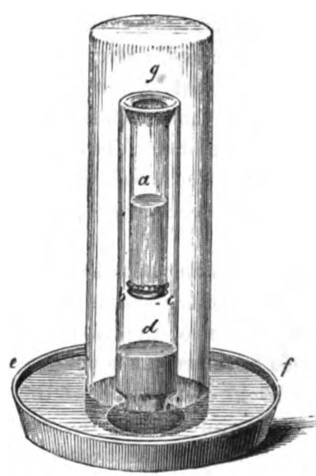
might enter or emerge. All that is necessary is, that these should be smaller than the interstices* of the limitary walls. It has certainly been supposed that blood-corpuscles, and particles of indigo or finely powdered charcoal, can pass directly through. But more exact observations militate against this notion. We can easily imagine that very small and angular pieces of charcoal may be accidentally driven into the blood-vessels under the influence of the pressure furnished by the intestine, and may then be washed off by the circulating blood. But the process is essentially exceptional, and affords no support to ordinary absorption.

501. We shall hereafter see that the porosity of animal membranes is capable of being altered by numerous collateral circumstances. The relaxation of the limitary walls probably leads to the enlargement of their interstices. These may also be dilated under the influence of very powerful pressure. One might thence imagine, that such extraordinary circumstances would allow of the exit of the blood or of other minute structures. But these unusual conditions,—the first step towards actual rupture, — constitute rare exceptions, which for the most part only appear in cases of disease.

FIG. 80.



502. Experiments on filtration may easily convince us how close is the normal texture of the animal membranes. If I close a tube *a* (Fig. 80), with the wall, *b c*, of the thoracic duct of a horse, covered by a stratum of red human serum (*a*) 26 inches high, and enclose the whole in the vapour apparatus, *e f g*, no blood-corpuscle (Tab. II. Figs. XXIV. to XXVI.), but only fluid, will pass through. Filtering paper which retains freshly precipitated oxalate of lime allows milk corpuscles (Tab. IV. Fig. LXXX. *a*) to pass through with a columnar pressure of 5½ inches; while the mucous membrane of the washed human small intestine does not afford the same result with a column of milk of ten times this length.

* It seems necessary to remind the reader that most of the organized membranes through which these fluids transude offer no visible interstices whatever, even to the highest powers of the microscope. In assuming such apertures we ought therefore always to remember, that it is only requisite that they should be larger than the atoms of the transuding fluids. And without pausing to inquire whether this physical condition might not sometimes be satisfied by the mere atomic grouping of the septum and fluid, we need only notice, that the ordinary colorific tests of dilute salts show the size of such atoms to be more minute than the mind can conceive of—*e. g.* something far smaller than the 100000000th of a cubic inch, in the case of the salts of iron.—*Editor.*

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503. We have seen (§ 130) that membranes moistened with water reject fluids,—such as quicksilver and oil,—which are not attracted by watery solutions. Hence we here meet with obstacles which may in many respects be compared with those offered by large solid bodies. It has certainly been believed, that the globules of quicksilver contained in mercurial ointment may directly enter the blood. But later researches are opposed to this view. The way in which fatty matters behave will shortly engage our express attention.

504. We will first consider the absorption of the alimentary substances, and will subsequently enumerate the peculiarities offered by the lymph.

If we introduce into the stomach a large quantity of spring water, containing a twentieth per cent of solid residue (§ 338), it will dissolve many of those organic matters which it meets with, and which the neighbouring juices of the body retain in a less dilute form. Thus the first current of diffusion is concerned with the nutrient and secreted fluids which moisten the coats of the stomach. But since these again are in contact with the walls of the blood-vessels and lymphatics, the blood and lymph must themselves be influenced within a short space of time.

The average watery content of human blood amounts to 79 parts per cent, and that of the lymph to about 93 or 94. Hence both of these fluids are more concentrated than the considerable quantities of water which we drink. They must therefore tend to dilute themselves at its expense. The blood, which contains more solid residuum, will hence act with greater energy than the lymph, which has a more watery constitution.

505. Setting aside the indeterminate influence exerted by the nature of the walls of the vessels and the other interposed tissues, it is evident that the process of diffusion must continue, until the densities of the two fluids have become equal to each other (§ 134). If all remained at rest, the blood and lymph of the walls of the stomach would thus be considerably diluted, and the remainder of water it contained would be correspondingly concentrated. But since the blood and lymph continue in movement, new portions of these denser mixtures are every instant exposed to the operation. Hence this arrangement, which also holds good for absorption generally, supports the interchange of the fluids in a very important manner.

506. We shall hereafter see that the lymph moves more slowly than the blood. Hence the favourable effect accomplished by this change of substance is less valid for it. And all this explains why the greater part of the water drunk enters the blood. The percentage of solid residue in the blood may thus be visibly decreased.

507. Drinks, — such as coffee, tea, lemonade, or wine, — give rise to similar phenomena. Alcohol and æther also easily enter the blood. A

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part of them is subsequently vaporized in the lungs, and at other free surfaces.

508. If a man takes a large quantity of an easily soluble substance, such as salt, the process of the phenomena may be followed with tolerable completeness. The fluids of the mouth, and the gastric juice (§ 434) which is poured forth in large quantity, will first dissolve as much as possible. Hence we first get a saturated solution of salt, which is therefore at any rate denser than the lymph and the nutritional fluid. This solution will next give off salt, and take up water. And if a certain quantity of the salt has remained undissolved, this also tends to form a concentrated brine. This process is repeated until the concentrated solution of salt is alone present. And the constant withdrawal of water at every instant may result in the sensation of thirst.

Putting out of consideration the unknown influence of the partitions which effect the diffusive process, it is evident that a time finally arrives, in which the solution of salt can act little or not at all on the blood, while it can still operate most energetically on the lymph and the nutritional fluid. And when its dilution has been thus effected, it is necessarily followed by a more vigorous interchange of action with the blood. So that we finally get phenomena similar to those that resulted from the introduction of the water which was so poor in solid constituents.

509. But this purely physical method of regarding the process is insufficient to a satisfactory explanation of all the phenomena which occur in the living body. Small quantities of salt, which are incapable of draining the entire mass of the blood in any considerable degree, nevertheless lead to remarkable feelings of thirst. This fact is very likely due to the circumstance, that this sensation may possibly depend upon local influences, exerted upon the nerves of the stomach by the blood. Larger quantities of a solution of salt which contains more of this substance than the blood itself not unfrequently produce diarrhœa,—probably in consequence of the irritating effect of the brine stimulating the organs of secretion, and exciting the vermicular movements of the alimentary tube. But although the purgative properties of large quantities of sulphate of soda or magnesia may be partially explained in the same way, still we are far from any sufficient explanation of the causes of the action of the different cathartics.

510. The fluids of the mouth contain about 99 per cent of water; and the gastric juice, which is poured out in larger quantity, about 98 per cent. Hence even supposing them to have extracted from the food, salts, dextrin, sugar, albuminous substances, or other compounds, still they will generally contain more water than the blood, and often even than the lymph. This explains why more dilute solutions generally disappear in the stomach itself (§ 454). It is possible that the acid character of the gastric juice may have some influence in this respect. Still there are at

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present no experiments on diffusion which are sufficiently trustworthy to allow even a theoretical decision of this question.

511. When the stomach has thus given up to the blood and the lymph all that it can communicate, there remains a more tenacious and resisting residuum. We have already (§ 455) seen that a part of this mass passes into the duodenum with the chyme.

512. In the duodenum a series of new watery solutions is added. The intestinal mucus originally contains only from 4 to 5 per cent of solid residuum; probably often less than this. The pancreatic fluid has 98 to 99, and the bile 87 parts of water. Hence we here meet with new sources of dilution. The watery solutions transmitted through this part take possession of these fluids, and absorption again begins. While the intestinal villi, which are richly provided with blood-vessels and lymphatics, increase the active surface. The vermicular movement maintains a continual change of the fluids which are undergoing absorption. The amount of influence exerted will evidently depend upon the relative values of the masses and times concerned in the operation.

513. Since the gastric juice leaves fat untouched, and, as it were, liberates it from the albuminous membranes in which it is sometimes contained, its absorption may possibly commence in the stomach. In point of fact, in the suckling rabbit we often find that the lymphatics of the stomach include a white fluid. But if the adult animal has eaten considerable quantities of fat, it is generally in the small intestine that the absorbents begin to contain any considerable quantity of white chyle. The lymphatics of the stomach are usually filled with a yellowish lymph; and at most, some of them exhibit whitish streaks.

514. The absorption of fat (Tab. II. Fig. XXVII.) is not yet sufficiently explained. Since the coats of the intestine are moistened by watery solutions, the present state of our knowledge forbids us to suppose that the fluid fats enter the blood or lymph by way of simple diffusion. For if this were the case, we might expect them to be already absorbed in the stomach; and large quantities of oil taken in the food could scarcely pass unchanged *per anum*. But however correct this reflection may otherwise appear, still we must remember that many glands secrete fluid fats, although their walls are saturated with watery solutions.

515. If all the fatty matters taken in at the mouth were converted into fatty acids, and into glycerin which is soluble in water, the process might be more easily explained. We have already seen in the study of digestion, that fatty acids are certainly capable of saponifying with the alkalies present in neighbouring fluids. The alkalinity of the blood and lymph would therefore favour its reception. But the special conversion of fat into chyle, and the microscopic constituents of this fluid which we shall presently refer to, speak rather against than for this opinion.

516. We have seen (§ 460) that the fatty ingesta undergo an ex-

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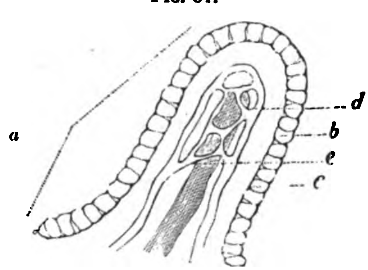
tremely minute division in the small intestine. If small oil-drops be brought into an albuminous solution, each of them becomes surrounded by a layer of albumen which has been called the haptogenous membrane. If the mucous or albuminous substances in which the smallest oil-globules are finally diffused act in the same way, we obtain a protective membrane consisting of watery combinations. This would facilitate the further passage of the molecules of fat by diffusion.

517. Under favourable circumstances the absorption of fatty matter may be immediately followed by the microscope. Let us imagine Fig. 81 to be a diagram of an intestinal villus, of which *a* is the epithelium, consisting of columnar cells (*b*) that clothe the whole. At *c* is the homogeneous limitary membrane, beneath which is the remaining structure that forms the basis of the villus. At *d* are the blood-vessels, and at *e* the lymphatics, which ascend in its centre.

Fig. 81.



We frequently find a large quantity of finely divided oil-globules closely adhering to the outer surface of the columnar epithelium. This latter structure is not thrown off during digestion, but is only removed as a consequence of maceration or of violent diarrhœa. The point of the villus is on this account seen dark by transmitted, and greyish-white by direct, light. According to some observers, the individual oil-globules enter into the interior of the columnar epithelia (*b*), and subsequently find their way to the vascular tubes which exist in the villus.

Fig. 81 renders it evident that, in such a course, they meet with the blood-vessel *d*, before coming upon the trunks of the absorbents which occupy the middle of the villus. But since the greater part of the fat passes into the chyle, it must either be to a great extent rejected by the blood, or be at once given off by it to the chyle.

518. The arrangement represented by Fig. 81 reminds us to a certain extent of some circumstances which will shortly be mentioned in speaking of the secreting glands. These contain a number of ducts, in the interior of which the secretion appears, while the blood-vessels which surround the exterior of the canal supply the necessary mother-fluid. We may conceive something similar to be repeated in the formation of the chyle. Hence this does not consist of a simple fluid of transmission, but of a mixture which is only produced under the influence of the blood. According to Fenwick, ligature of the blood-vessels renders the formation of a normal chyle impossible.

519. Although the absorption of the liquefied food and of the mixtures

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which are added to it proceeds along the whole course of the large intestine, still the processes here met with are similar to those exhibited in the stomach and small intestine. But though the absorbents can take up watery solutions or fats, yet under ordinary circumstances, white chyle is not formed here.

520. The introduction of food renders the intestine the most frequent recipient of foreign fluids. But absorption may also obtain in every other part of the body, to a greater or less extent.

521. Since the skin is dry, and, until moistened, only allows liquids to pass through it with great difficulty, these only begin to be rapidly taken up after the complete moistening of the epidermis. Hence it depends on the time that a man has remained in a bath whether any of the compounds dissolved in it have entered the juices of his body, and how much has thus been absorbed.

522. Parts which are provided with very delicate integuments, such as the conjunctiva of the eye, allow absorption to go on with greater ease and rapidity. But we are altogether devoid of sufficient comparative observations on the behaviour of the different mucous membranes in this respect. The imperfect action sometimes exhibited by solutions introduced into the ramifications of the air-tubes, indicates that differences do obtain, which could not have been safely predicted.

523. In endermic experiments we seek to obviate the difficulties which the dry skin opposes, by its removal. For instance, we first produce a blister by cantharides, and after removing the epidermis raised by the effused fluid, we strew upon the moistened surface the remedies, the action of which is desired—such as morphia or veratria.

524. Solid deposits,—such as inflammatory exudations, or deposits of pus which have penetrated between the internal parts of the tissues,—are not unfrequently liquefied and absorbed. But nature frequently fails in this attempt, even although aided by the alkaline or saline character of the neighbouring juices. In many cases a solid residuum which has been thus corroded for years still obstinately remains. Foreign bodies which have been introduced by accident,—such as needles, knife-points, or bullets,—resist with equal frequency and success. Not unfrequently, new exudations surround them with a capsule. It may also happen that they are gradually urged forwards through the softer tissues.

525. From what has been previously brought forward it follows, that the matters absorbed may either pass at once into the blood, or may first enter the chyle or the lymph, or, finally, may pass into both these fluids simultaneously. But a great deal of this uncertainty depends, not so much on the nature of the proffered compounds, as upon the existing density of their solutions, and even upon the places at which they are absorbed. Many salts, especially those of the metallic combinations, as well as sugar, lactic acid, and many albuminous bodies, are thus liable

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to great variety of action. The few experiments hitherto made seem to indicate, that the transit of some substances essentially depends upon their chemical constitution.

Alcohol, and colouring matters—for instance, turmeric or madder—enter more easily into the blood than into the chyle. The latter also seem to be more frequently found in the lymph than in the chyle. We have already seen (§ 499) that fatty substances are taken up in large quantity by the absorbents, and that the milky appearance of the chyle principally depends upon these. Hence it is absent in the fasting state, as well as after the use of food which contains no fat, and out of which no considerable quantity can be produced in the course of the digestive metamorphosis.

526. Narcotic poisons, such as strychnine, kill much more quickly when the circulation is so free, that their transit into the blood is unimpeded. On the other hand, if a ligature be applied to the aorta of a rabbit, immediately below the origin of the two renal arteries, and so that the circulation in the hind legs is in great part obstructed, still, in spite of this, the introduction of strychnine into a wound of the thigh induces convulsions and even death. The only difference is, that the result is less rapid and complete.

527. Since both chyle and lymph are sooner or later mixed with the blood, the question intrudes itself—Why has nature provided absorbents as well as blood-vessels? A consideration of the course of the lymphatics may best enable us to answer this question.

528. The absorbents of the small intestine principally take their rise in the intestinal villi. If we examine them during the period of digestion, we frequently see central vessels, which are filled with white chyle, and appear finally to dilate into club-shaped extremities. But more successful observation shows bifurcating branches, and mutual communications between the primary tubes. If the valves hereafter to be mentioned offer no important obstacle to their backward or peripheral injection, we may sometimes succeed in exhibiting the absorbents, as beginning by numerous reticulations—such as may, for instance, be seen on the surface of the horse's liver. These appearances are at any rate more trustworthy than those blind extremities of the absorbents which are described by some ancient and modern authors as visible with the naked eye. Still it must be admitted that we are as yet absolutely ignorant of the mode in which the absorbents begin in most parts of the body.

529. Be that as it may, we next meet with trunks which, passing onward, either join with each other to form a dense network, or are at least united together by large transverse branches. They subsequently enter the various lymphatic glands, which are coils of lymphatics with numerous blood-vessels distributed between them.

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530. Occasionally some of the lacteals of the mesentery or of other parts open immediately into subordinate venous branches. But the thoracic and cephalic ducts form the chief conduits which transmit the chyle and lymph into the blood.

531. The lymphatics which ascend from the legs, the pelvis, and the hypogastrium, first unite to form the receptaculum chyli (*a*, Fig. 82). This then passes into the thoracic duct (*b*), which also receives the remaining lymphatics of the belly and the greater part of the chest, together with some of the branches coming from the arm. It forms the largest lymphatic trunk, and finally empties itself into the union (*e*) of the left jugular (*c*) with the left subclavian vein (*d*).

Fig. 82.

The cephalic trunk (*f*, Fig. 82), into which open the lymphatics of the head and neck, and of part of the arms (*g*), passes into the common truuk (*k*) of the right jugular and subclavian veins. It in some degree fills up the void left on this side by the thoracic duct.

532. Hence the chyle avoids the passage which leads through the liver. The veins of the stomach and intestine open into the portal vein. But this again ramifies in the liver. So that those alimentary matters which enter the blood pass to this bile-secreting gland. But the chyle does not enter the liver, since it is mixed with that part of the venous blood which immediately enters the right half of the heart, and passes from hence into the lungs.

533. Since the portal blood is thus applied to the preparation of bile, matters which have been already taken up by the blood may be again returned with the bile to the intestine. Sugar, fats, and albuminous matters, probably undergo this circulatory movement. Still we are justified in conjecturing, that the greater part of the matters taken up in the portal blood pass onwards into the hepatic vein, and hasten into the right side of the heart through the inferior vena cava.

534. The chief object of the lymph and chyle appears to be that of ensuring a normal admixture of the blood. When this latter fluid passes through the capillary vessels of the various parts of the body, it permits the exsudation of a mixture which is more dilute than its own serum, and which is called the nutritional fluid. This permeates and

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moistens the tissues, surrendering to them the necessary substances, and, for the time, taking up less useful combinations in their stead. In this way we get a residuum which is more watery than before, being poor in useful materials, and only rich in those which are for the moment unsuitable. Now if this passed into the blood it might easily change its quality. The absorbent canals are probably intended to withdraw this fluid. Their contents are gradually improved by a process of diffusion with the blood; and the lymphatic glands probably play a very essential part in this respect.

535. The fact, that a large portion of the fatty matters passes into the chyle, is probably dependent upon similar causes. While normal chyle exhibits innumerable fatty molecules, no mechanical admixture of these can be detected in the blood. Hence the chyle probably conveys the fat in a condition different from that which the blood could do. It is not applied to the preparation of bile, but, on the contrary, immediately after its exposure to the influence of the blood, it reaches the lungs, the respiratory furnace to which fresh oxygen is continually being conveyed.

536. Since that metamorphosis of the nutritional fluid which forms the chief source of the preparation of lymph varies according to the total quantity of blood, and the porosity of the walls of the vessels and the tissues of the several organs,—it is obvious that the character of the lymph will differ according to the part of the body from which it comes. But this difference is necessarily less in the principal trunks of the absorbents, since fluids from many sources are here already mixed, and the influence of the lymphatic glands has also been interposed.

537. A peculiar disease sometimes affords us an opportunity for collecting human lymph shortly after its origin. If a lymphatic trunk of the toes or leg has been cut through, it sometimes happens that the wound will not heal, so that lymph continually streams from the opening. And occasionally it is only by very energetic measures, such as the excision of the whole neighbourhood, and subsequent actual cautery, that cicatrization can be induced.

538. In the observations made by J. Mueller and Nasse, Marchand and Colberg, the clear yellowish or greenish-yellow lymph coagulated in the air after some time. Here the mixture had flowed from a lymphatic trunk of the foot. The colourless clot produced within its serum contained a large number of lymph-corpuscles. The yellowish fluid which the author obtained from a wounded lymphatic of the upper third of the anterior part of the leg, close to the angle of the tibia, scarcely coagulated at all. And portions of the same fluid which had been kept hermetically sealed maintained their fluid state for more than twenty-four hours. Microscopic examination showed but a very few granular corpuscles; they were for the most part not quite spherical, but some-

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what flat. No large free oil-globules were ever seen. On allowing the whole to stand some time in an air-tight pipette, it deposited a large number of extremely small molecules (*b c*, Tab. II. Fig. XXII.). Besides these were remarked a sparing number of granular and partly flat and irregular corpuscles (*a*), crystals of cholesterine (*d*), and other indeterminate compounds (*e*). These constituents were also verified a year afterwards.

539. Since even the primary lymph varies, it is very difficult to decide what changes are produced by the lymphatic glands; a difficulty which is increased by the fact, that chemical research is at present unable to investigate these delicate metamorphoses.

The primary human lymph contains from 3 to 5 per cent of solid residuum, while the living liquor sanguinis seems to have on an average about 9 per cent. The latter also contains larger quantities of albumen, but proportionally less salts. Still the composition of the lymph seems to approximate more to that of the liquor sanguinis, the further it passes onwards. We then find a larger quantity of albumen, and perhaps of fibrin, together with more numerous lymph corpuscles; and now and then cells with single nuclei, and corpuscles which are nearly or quite identical with those of the blood. These phenomena may be best seen in the contents of the thoracic duct of fasting animals. Sometimes the yellow or white mass of the lymph becomes of a red colour by exposure to the air or oxygen gas.

540. The chyle contains a great number of very small and probably fatty molecules, with which are also found some oil-globules of middling size, and the bodies called chyle corpuscles. These latter are granular spheres, which under the influence of water frequently exhibit a membrane enclosing a nuclear mass. Their number seems to be increased by the passage of the fluid through the mesenteric glands. If a person has taken large quantities of milk shortly before death, the contents of the thoracic duct sometimes exhibit larger drops of oil, which easily run together and unite.

541. We are justified in supposing that the blood, flowing under a certain pressure, continually allows particular compounds to exsude through the porous walls of its vessels. The nutritional fluid may either give off the proper substances to the tissues, or may merely pass through them as an aqueous wash. In either case considerable quantities of fluid will be taken up by the lymphatics. And if we remember how much fluid is consumed by the glands during the time they actually discharge their functions, although only traces are secreted during their state of rest, we shall be justified in concluding that large quantities daily pass through the conduits of the lymphatics.

542. It has hitherto been found impossible to determine even approximatively the quantities of chyle or lymph which are added to the

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blood in twenty-four hours. The mode of proceeding made use of for this purpose allows of considerable uncertainty.

543. It has been supposed that the azotized constituents of the food pass exclusively into the chyle, since the blood at the same time allows the exudation of albuminous substances which it will not instantly resume. But this presumption is based upon no secure foundation, since the chyme generally contains other modifications of nitrogenous compounds. We have already seen that a part of these probably enters the blood.

Were it not for this objection we might tolerably estimate the daily quantity of chyle from the amount of azotized food taken, and the nitrogenous contents of the pure chyle. In this way Vierordt [14]) obtained about 4½ to 7 pounds as the quantity for an adult man in the period of twenty-four hours. But an accurate determination is at present difficult, since not only have we no exact elementary analyses of the human chyle uncontaminated by lymph, but the azotized compounds of the food are by no means equivalent to each other, while the fatty substances present exercise an important influence, and many other bodies,—such as sugar or salts,—are by no means without effect upon the results.

544. Bidder attempted to ascertain the quantities of fluid which flowed from the severed thoracic ducts of recently killed carnivora in a given space of time. Taking a minute as the unit of time, cats gave 4·42 to 7·68 grains, and dogs 25·67 to 43·17 grains. Extending these results over twenty-four hours, we get 8540 grains=1 pound 3¼ ounces, or almost 1-8th of the average weight of the body, for the cat: and 49420 grains=7 pounds 1 ounce, or from 1-7th to 1-8th of the whole body, for the dog. The quantities brought by the cephalic duct must be additionally taken into account. But it is easy to see that such an estimate is a very insecure one; since the lymph flows under very different circumstances in the killed and the living animal, and all the errors of observation which occur within the few minutes of the experiment are greatly multiplied in the calculation for twenty-four hours.

545. The origin of the lymph previously described (§ 504 *et seq.*) warrants us in concluding, that the beginnings of the lymphatics are constantly and rapidly taking up fresh quantities of fluid. These next distend the vessels to the maximum which their circumstances will allow, and then drive onwards the columns of fluid which lie before them. The fluid continually taken up thus furnishes a *vis à tergo*, which constantly urges the chyle and lymph towards the blood. Hence the contents of the lacteals probably pass onwards more quickly at the period of digestion, when large quantities of chyle are being furnished, than when the distension of the mesenteric absorbents is limited to a mere formation of lymph depending upon the nutritive conditions.

546. On looking at an absorbent trunk which is filled with quicksilver or hardened wax, we see dilatations separated by intervening con-

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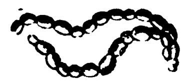
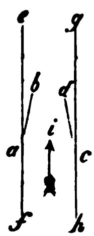
strictions, which occur at comparatively short distances from each other. Fig. 83 shows this appearance as seen of the natural size in the lymphatics of the human pelvic cavity. The constrictions correspond to these points at which valves occupy the interior.

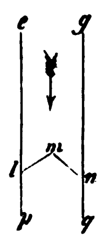
FIG. 83.



547. The diagrams at Figs. 84 and 85 represent the mechanism of the valves. The proper course of the lymph is centripetal, *i.e.*, in the direction from the beginnings of the absorbents towards the points of their opening into the veins. Let us suppose *e f g h* (Fig. 84) to be an absorbent, the pouches *a b* and *c d* are so arranged that their free cavity, *e a b* or *g c d*, looks towards the end, *e g*, which lies nearer to the vein. Now if the lymph flows centripetally, and takes the direction indicated by the arrow in Fig. 84, the force of the current of liquid presses the valves *a b* and *c d* against the walls *ef* and *g h*. It thus obtains the greatest possible space for transit (*i*, Fig. 84).

FIG. 84. FIG. 85.





But if, on the other hand, the lymph sinks back in the centrifugal direction indicated by the arrow in Fig. 85, it is caught in the open cavities, *e a b* and *g c d* (Fig. 84). These become filled with fluid. But *a b* and *c d* are of such a length that they come into contact by their inner margins, or by a part of their internal surface. A partition (*l m n*, Fig. 85) is thus produced which renders all further reflux impossible.

548. The valves follow each other at comparatively short intervals. The greatest distance between two of the constrictions represented in Fig. 83 is usually 2-5ths of an inch in man, and 4-5ths in the horse. This has the advantage of cutting off small columns of fluid, so that the reflux of lymph in any considerable quantity is an impossibility. The weak and somewhat variable forces by which the lymph is moved onwards explain this arrangement.

549. While the large absorbent trunks are plentifully provided with such valves, they are frequently absent from the commencements of the lymphatics. They cannot be detected in the lacteals which run in the middle of the intestinal villi (§ 517). They prevent the injection of any of the larger absorbent trunks in a centrifugal direction. But in that network of absorbents which exists on the surface of the horse's liver, the attempt succeeds (§ 528).

550. The lymphatic system possesses no structure analogous to a heart, the pressure of which can urge the chyle or the lymph in the centripetal direction. The lymphatic hearts of reptiles are situated at the point where the absorbents pass into the venous stems. Hence they press the lymph into the blood with renewed force. Since they are so

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constructed that the blood cannot pass into them centrifugally, they can at most only fill with lymph at the instant of their relaxation. They thus indirectly contribute to the normal progression of the lymph.

551. This want of a special forcing-pump for the absorbents alone is the cause why the lymph flows more slowly, and, as it were, uncertainly, than the blood. The velocity of its current also probably varies greatly at different times, since there are numerous forces which assist its movement, but which only come into play at particular periods, and operate with unequal energy.

552. The frequent repetition of the valves has this advantage, that each smallest column of fluid is completely gained for the progressive movement, as soon as it has but passed beyond the margin of the closely fitting valve. The *vis à tergo* which is furnished by continual absorption is thus greatly supported. And every other pressure which any collateral circumstance can afford, is, in like manner, rendered conducive to the same object.

553. It has been frequently conjectured that the coats of the absorbents possess an independent faculty of contraction. But at present it is only by the aid of hypothesis that we can suppose this to have any relation with the movement of the lymph. Experiment does not as yet afford any secure indication of such a force.

554. A vermicular movement never occurs in the absorbents. For instance, if we lay bare a large and distended lymphatic in the neck of a horse, it is usually at first unchanged. At most it is constricted by the air, and so slowly, that the naked eye is unable to notice the gradual alteration of its diameter. On the other hand, we find that the absorbents of recently killed animals empty themselves from a gradual diminution in their size. But even were this supposed to prove that the lymphatics sometimes alter their calibre, such a force, favoured by the arrangement of the valves, might certainly support the current of the lymph, but it could not constitute the exciting cause upon which it originally depends.

555. The contraction of the muscles furnishes a force of pressure which the yielding walls of the absorbents readily obey. And since all reflux is cut off by the valves which follow each other at short intervals, this collateral cause furthers the passage of their fluid contents in the centripetal direction only.

556. Lieberkuehn and Poiseuille have remarked that the chyle contained in the mesenteric absorbents of the young mammalia (*l* and *k*, Fig. 76), is impelled onwards by the vermicular contraction of the corresponding piece of intestine (*a d*), and, after its cessation, appears to return to a state of rest. Those muscles of the body which are in immediate contact with lymphatic trunks are capable of exerting the same influence. An external pressure, or even the mere flexion of some

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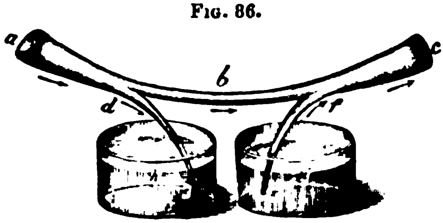
parts of the body must, from the arrangement of valves mentioned, result in the expulsion of the contents of the absorbents to a corresponding extent.

557. The thoracic duct (*b*, Fig. 82) opens into the point of union, *e*, of the left jugular and subclavian veins *c* and *d*; and the cephalic duct, *f*, into the junction, *k*, of the corresponding veins of the right side, *h* and *i*. Hence we find here two peculiarities. The veins which receive the terminal trunks of the lymphatic system lie in the neighbourhood of the heart, within the cavity of the chest. And two large veins unite to form a common trunk where the chief absorbent tubes enter. This arrangement may be theoretically shown to support the movement of the lymph.

558. It has already been remarked (§ 106) that, other circumstances being equal, the velocity of a current of liquid increases in inverse proportion to its transverse section. Now, since the sum of the transverse sections of *c* and *d* is greater than that of *e*, and the sum of *h* and *i* also greater than that of *k*, it follows that the absorbent trunks open into venous cavities in which the velocity of the movement of the blood is experiencing an instantaneous increase.

Let us suppose that *a b c* (Fig. 86) is a tube provided with side branches, *f h*, that *d e* dips into colourless, *h*, and *f g* into coloured, water *i*. If the whole system, *a b c*, *d e*, and *f g*, be filled with water, and the fluid sent

FIG. 86.



through it with the necessary velocity, it will come out coloured at *c*. Hence the coloured water at *i* has been sucked up through *f g*. The current of fluid hurrying through *b c* produces a force of suction,—a kind of negative pressure—in *f g*. The hydraulic theory of Bernouilli-Venturi satisfactorily explains this phenomenon.

The venous blood falls into the neighbouring right ventricle at the time of its diastole. That narrowing of the transverse section of its current which was mentioned above, raises the velocity—one of the main conditions of this negative pressure—at the point where the ends of the lymphatic system open. These are burdened with the weight of their neighbouring structures, and the latter are in their turn exposed to the pressure of the atmosphere (§ 94); so that if the negative pressure operate with sufficient force, lymph will advance from the thoracic and cephalic ducts into the corresponding veins.

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559. When the thorax is enlarged during inspiration, all the neighbouring fluids taking a centripetal course in the different vessels are attracted. While conversely, the act of expiration tends to repel them with a certain force. But since the chief terminations of the absorbents lie in the thorax, inspiration will tend to conduct the lymph towards its goal. While the valves prevent expiration from producing a corresponding disturbance, and the same effect is also partially produced by the reaction of the abdominal muscles.

560. Ludwig and Noll [15]) inserted a tube connected with the hæmadynamometer (§ 86) into a large absorbent—such as one in the neck of a dog. They found that the indicating column showed certain deviations corresponding with deep respiratory efforts. During the act of inspiration a negative, and during expiration a positive, pressure appeared. But if a ligature was applied to the peripheric part of the absorbent, no negative pressure, and hence no absorption, was shown by the hæmadynamometer. This probably depends on the fact, that the quantities of fluid necessary to equal and neutralize the negative pressure may proceed from other open columns of liquid. The suction of a short tube with a blind extremity always requires much more force than that of a system of tubes, the access to which stands open.

561. But none of these collateral circumstances can do more than assist the movement of the lymph. And our present knowledge of this as yet undecided subject leads to the conjecture, that its original source lies in the continuous process of absorption. The frequent valves not only allow casual muscular movements to be made useful, but prevent them driving back the lymph, or introducing blood from the veins into the absorbents. The elasticity of the walls of the lymphatics permits their instantaneous extension, and the reflection of a certain pressure; while it leaves the current completely free. Their capacity of contraction forms the most obscure point of all. No rapid change of diameter is ever produced by its influence. Hence it can at most gradually alter the size of the channel; and rather affects the circumstances of capacity and elasticity, than the then existing movement.

562. We shall hereafter see that the force of the current (§ 86) of the blood varies greatly with the different blood-vessels in which it is contained. The absorbents exhibit even more considerable variations of this kind; since there are great varieties in the amount of absorption, as well as in the influence of the muscular movement or other accidental forces then existing. The slow progress of the lymph would, *à priori*, allow us to expect a very small degree of pressure and velocity (§ 102).

563. Hitherto no attempt has been made to determine by means of the hæmadynamometer the amount of pressure in the absorbents of larger mammalia, such as the horse. Ludwig and Noll, whose observations were made upon dogs and cats, found a pressure of about one to

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four-tenths of an inch of water. If a fluid be injected into the arteries in a peripheric direction, the more energetic absorption which follows raises the index-column of the hæmadynamometer. Similar phenomena are produced by muscular contraction, by the movement of particular parts, or by an artificial pressure from without. The changes which may be brought about by the beat of the heart, and by the respiration, probably diminish in the several absorbent trunks, the farther these are distant from the chest.

564. Hitherto the velocity of the movement of the lymph has not been directly determined by any large series of experiments. Cruikshank [16]) states that he has seen chyle flowing in the lacteals of a dog's mesentery with a velocity of four inches in a second. A more accurate estimate of this kind would be so far valuable as that it would allow us roughly to calculate how much of this fluid generally passes into the blood within 24 hours.

565. Since the sum of the cavities of the subordinate absorbents is greater than that of their trunks, and since the chyle and lymph thus pass from a wider into a narrower channel — other things being equal, the velocity will gradually increase. The absorbent glands delay the course of the lymph from a twofold cause. They enlarge the total channel of the fluid; and, on account of their winding course, constitute new obstacles. Hence this greater amount of resistance must consume more velocity (§ 103). The long delay of the lymph in these glands, allows it to be more closely assimilated to the blood. The quicker movement which we meet with in the larger trunks offers the converse advantage. The particles of the fluid are here enabled to pass away so swiftly as to be prevented completing their diffusion with the blood of the neighbouring vascular trunks.

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CHAPTER VIII.

CIRCULATION.

566. The mass of the blood is constantly circulated in closed channels; in order that it may everywhere give off the matters necessary to the secretions, to maintenance, and to growth; and may itself gradually become renovated under the influence of the air. This twofold object corresponds to those two chief sections of the entire circulation which are called the systemic and pulmonic.

567. The heart forms the centre or chief agent of this function. It drives the blood in the peripheric or centrifugal direction within special tubular conduits, the arteries. It receives the blood again by the veins, within which the fluid returns with a centripetal course. The fine network of the capillary vessels forms a transitional structure between these two opposed kinds of conduits—between the efferent arteries, and the afferent veins. The blood thus takes a curved course in their interior, from the peripheric to the central direction.

568. The adult human heart is represented by Fig. 87 as seen anteriorly, by Fig. 88, posteriorly. In both it is 3-8ths of the natural size. It consists of four muscular sacs, the two atria or auricles (*c* and *d*, Fig. 88), and the two ventricles (*a* and *b*, Figs. 87 and 88). The right auricle (*c*, Fig. 88), and the right ventricle (*a*, Figs. 87 and 88), together form the right heart; and the left auricle (*d*, Fig. 88), and the left ventricle (*b*, Fig. 87 and 88), the left heart. Each auricle is connected with its corresponding ventricle by a wide opening, the auriculo-ventricular aperture. The partition between the two auricles, and that between the two ventricles, completely shut off the right from the left heart.

569. This arrangement is repeated in adult mammals and birds. While in the higher reptiles—for example, in the serpents—we find that the two ventricles communicate by a gap in their common septum. Frogs have only one ventricle, and that a simple one: but their auricles are separated internally into two. Fishes possess only one auricle, and one ventricle. Here a special muscular covering possessed of independent contractile powers—the bulbus arteriosus (*f*, Figs. 98, 99, p. 185)—frequently encircles the commencement of the arterial trunk where it leaves the ventricle. We shall hereafter see that the human and mammalian heart gradually go through all these changes in the course of embryonal development.

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570. The pulmonary artery (*c d*, Fig. 87) springs from the right ventricle, while the pulmonary veins (*l m*, Fig. 88) empty themselves into the left auricle. Since the right heart of the adult is shut off from the left, the blood, which has to pass from the right ventricle (*a*, Fig. 87)

FIG. 87.

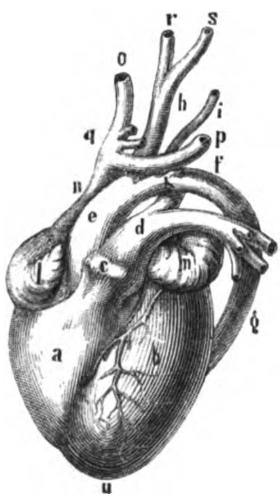
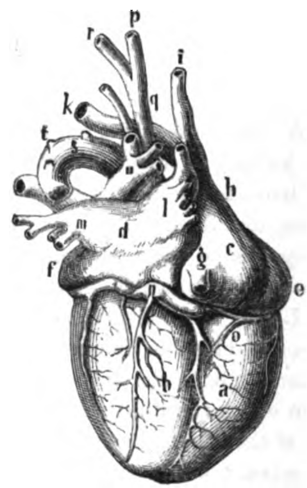


FIG. 88.



into the pulmonary artery, *c d*, must flow through the lungs themselves, before it can return to the left auricle (*d*, Fig. 88). The principal artery of the system, the aorta (*e*, Fig. 87), arises from out of the left ventricle, *b*. But the superior and inferior vena cava (*h* and *g*, Fig. 88) open into the right auricle, *c*. Hence the intervening route must be formed by the different parts of the body. In this way we get a small or pulmonic circulation, which connects the right ventricle, *a*, with the left auricle, *d*; and a great or systemic circulation, which connects the left ventricle, *b*, with the right auricle, *c*.

571. The diagram, Fig. 89, may serve to represent the directions taken by the current of the blood. The blood present in the right auricle, *c*, passes into the right ventricle, *a*, then into the pulmonary artery, *e*, and the capillary vessels of the organs of respiration, *f*, in order to return through the pulmonary veins, *g*, to the heart and left auricle, *d*. It then passes into the left ventricle, *b*, and from thence arrives at the systemic aorta, *h*. The different arteries which arise from this vessel conduct the blood to the various organs of the body. One part of these, *i*, conduct it through their capillaries, *k*, into the superior vena cava, *l*; while another part, *m*, impels it through their capillaries, *n*, into the inferior cava, *o*. Both venæ cavæ, *l* and *o*, pour their blood into the right auricle, *c*, where the circulation just described recommences. The arrows in Fig. 89 indicate the directions of these currents.

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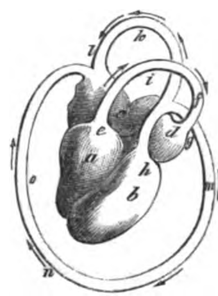
572. The right ventricle, *a*, the pulmonary artery, *e*, the capillaries of the lungs, *f*, the pulmonary veins, *g*, and the left auricle, *d*, all belong to the small respiratory or the pulmonic circulation; while the left ventricle, *b*, the aorta, *h*, the arteries of the body, *i m*, the capillaries, *k n*, and the veins of the body, *l o*, and the right auricle, *c*, belong to the greater or systemic circulation. And since the right heart, *c a*, of the adult man is completely shut off from the left, *d b*, the blood must pass along each of these paths successively, before returning anew to the same part of the heart. When it has completed its systemic path, it necessarily passes through the lungs before returning to its previous route.

Fig. 89.



573. This change is intimately connected with the requisite renovation of the blood. This fluid, as it leaves the heart by the systemic arteries, *i* and *m*, is arterial or bright red in colour: while that returning by the systemic veins, *l o*, is dark red or venous. The capillaries, *k n*, of the organs of the body chiefly give off the substances necessary to its maintenance. And at the same time the blood here changes its colour, the bright red arterial being converted into the dark red venous blood. But as the latter can no longer fulfil the objects of nutrition, it passes by the pulmonary artery to the organs of respiration. And in the pulmonary capillaries, *f*, it becomes bright red under the influence of the respired air. The pulmonary veins then conduct this renovated blood to the left auricle, *d*; and from hence it enters the great circulation.

574. The walls of the arteries are distinguished by a high degree of elasticity (§ 61); those of the veins by their yielding character. But from what was above stated, it appears that the pulmonary artery *e* (Fig. 89), conveys dark red blood, and the aorta, *h*, together with the arteries of the body, *i m*, bright red blood: while, conversely, the pulmonary veins, *f*, contain arterial blood, and the systemic veins, *l o*, dark red blood. Comparing this with the directions of current indicated by the arrows, it is evident that these, and not the characters of the blood itself, determine the nature of the conducting tubes. The contents of all arteries take the peripheric, and that of all veins the centric, direction, quite irrespectively of their bright or dark red colour. But since the direction of the stream is connected with the mechanical circumstances of the circulation, while its colour depends upon chemical relations, it is evident that the nature of the coats of the vessels is determined by the former.

The capillary vessels enforce the same conclusion. The blood bends from its peripheric to its centric course in the capillaries of the lungs,

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just as it does in those of the body: at *k* just as at *n*. Hence we meet with no essential difference of structure. The dark red blood of the pulmonary artery *e* (Fig. 89), becomes bright red in the capillaries of the lungs; and the bright red blood of the systemic arteries, *i m*, becomes dark red in the capillaries of the body, *k n*.

It is at the same time obvious that the two halves of the heart contain different kinds of blood. The right heart, *c a*, contains dark red or venous, the left, bright red or arterial, blood. If each circulation be so isolated that its two extremities exhibit blood of opposite colours, and if this separation of the two be extended into the heart itself, the right ventricle, *a*, and left auricle, *d*, will appertain to the pulmonary, and the left ventricle, *b*, and right auricle, *c*, to the systemic, circulation. Hence we have here a kind of mutual decussation, which secures an alternation in the waste and renewal of the blood (§ 566).

575. The heart forms a forcing and sucking pump which drives its contents onwards through the tubes of the vessels. Its strong muscular wall endows it with a capacity of alternate contraction and extension. Its contraction furnishes the force of pressure which impels the contained blood; while its relaxation affords space for the entry of a new supply. The two states of contraction or systole, and relaxation or diastole, continually alternate with each other. A beat of the heart comprises that space of time, in which each of its four chief compartments has undergone one systole, and one diastole.

576. The two neighbouring auricles (*c* and *d*, Fig. 88) contract simultaneously, and subsequently relax again at the same instant. This also occurs with the ventricles, *a b*. But the auricles, *c d*, are in the state of contraction or systole, when the ventricles, *a b*, are in that of diastole or rest, and *vice versâ*. Every pulsation of the heart is hence divisible into two chief parts, in which the auricles exhibit a state opposite to that of the ventricles.

577. This alternation has a definite object. Let us suppose the auricles (*c* and *d*, Fig. 88), which have received their blood from the veins, to contract; their contents will easily enter into the simultaneously relaxed ventricles. But when the ventricles are subsequently diminished in size, in order to the transfer of their contents into the arteries, the auricles at the same time acquire, by their relaxation, the yielding character which is necessary to allow of the entrance of new quantities of blood. Hence the alternate activity of the auricles and ventricles allows each segment of the heart to work in such a way as to prepare for the action of the next portion in the instant which immediately succeeds.

578. Since the pulmonary and systemic circulations form two divisions of the whole path of the blood, which are only united in the heart, it becomes explicable why every two similar segments of the heart offer corresponding states of contraction or relaxation at the same instant. If

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both ventricles contract, a certain quantity of blood is impelled into the aorta and the arteries of the body. These propel corresponding quantities into the right auricle. And if other portions of blood did not simultaneously pass onwards into the pulmonary artery and the left auricle, an irregularity in the forward movement would be introduced, which would finally lead to great disorder. But the simultaneous action of the two results in a continuous flow of the blood.

579. The blood which is contained in the lungs gives off carbonic acid and water, while it takes up oxygen. That of the systemic capillaries furnishes the combinations necessary for the secretions and for nutrition: and in doing so the carbonic acid which it contains is increased, while its oxygen is diminished. These changes produce a certain alteration in the bulk of the entire mass of blood. But if we consider that each stroke of the adult heart occupies less than a second, and that a quiet respiration lasts on an average four times as long, it will follow that the change which corresponds to a single pulsation can be but very small. So that putting it altogether aside, we may suppose that the right ventricle propels just as much blood into the pulmonary artery, as the left into the aorta. That is:—the two ventricles have the same capacity during perfect diastole, and completely empty themselves during systole in the peripheric direction. But since the contraction of a ventricle can at most only propel as much blood as it has received from the auricle, this leads us to the further supposition, that the capacity of an auricle during diastole coincides with that of a ventricle during the same state, or, at any rate, only exceeds it by so much as may regurgitate into the veins. It is therefore extremely probable, that all four of the cardiac cavities contain about the same quantity of blood during life.

580. An examination of dead bodies appears not to confirm these opinions. We generally find, that the right ventricle forms a cavity of larger dimensions than the left; while the ventricles include a larger space than the auricles and their auricular appendages (*l* and *m*, Fig. 87; *e* and *f*, Fig. 88, p. 184). But a closer investigation teaches us that these facts do not refute our previous assumption. The muscular mass forming the wall of the left ventricle (*t u*, Fig. 91, p. 178), is twice as large as that of the right one (*t*, Fig. 90). The heart of a corpse is generally contracted to a certain extent,—a contraction which depends upon elasticity, the *rigor mortis*, or both of these causes together. Hence the cavity of the left ventricle is smaller than that of the right. To this it may be added, that the latter usually contains more blood, since the right heart generally dies later than the left.

The auricles of the living animal are extended during diastole to their greatest size. But this state does not continue after death. This explains the smaller size of their cavity. It must however be admitted,

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that the view which ascribes to them the same capacity as that of the ventricles is only founded on the supposition that the ventricles must receive as much blood as they expel in the following instant. And this supposition is, as yet, rendered insecure by the complicated,—and as yet partially unknown,—relations of capacity and velocity in the peripheral channels of the blood.

581. The contracting or relaxing muscular fibres furnish the forces by means of which the heart acts as a forcing and sucking pump. But it is only by a twofold assistance that this organ accurately fulfils all the duties imposed upon it. Its several masses of muscle are suitably divided and arranged. And the course of its fluid contents is regulated by proper valves, which prevent them from passing in any but the peripheric direction.

582. The chief masses of muscular fibre, and the morphological relations most important to the circulation, are represented in Figs. 90 and 91, which give a view of the opened auricles and ventricles of the heart

FIG. 90.

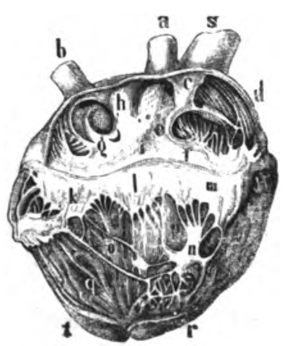

FIG. 91.

shown at Figs. 87 and 88. Fig. 90 is the right heart, laid open along the angle of its right side; and Fig. 91 is the left heart, slit up along its left side. It may be seen that there is an essential difference in their subordinate features. The left auricle is smoother interiorly (*e* Fig. 91) than the right. The arrangement of the *carneæ columnæ* (*n o*), and muscular reticulations (*q r* Fig. 90), of the right ventricle is also different from those of the left (*o p* and *r s*, Fig. 91).

583. The right auricle receives the bulk of its blood from the superior and inferior vena cava (*a* and *b*, Fig. 90). Less considerable quantities are derived from the substance of the heart itself, through the aperture of the great cardiac or coronary vein at *g*, and the "*foramina Thebesii*" of the small cardiac veins, (*e*, Fig. 90). The "*tuberculum Loweri*," *h*, which is placed above the *fossa ovalis*, *g*, prevents the streams of the two venæ

cavæ from interfering with each other. That of the superior vein is thus led downwards, while that of the inferior is turned aside towards the region of the auricular appendage. The intervals between the *musculi pectinati* of the auricular sinus and the auricular appendage are so thin, that they allow of very considerable extension. And in children in whom the heart is exposed by a congenital malformation, the auricles and auricular appendages have been remarked to be extremely distended at the instant of diastole.

584. On the right auricle contracting at the instant after diastole, the auricular appendage strives to propel its blood into the sinus, while this cavity makes every effort to empty itself. In this act the *musculi pectinati* (*f d*, Fig. 90) assist to evacuate the cavities which intervene between them. Since the mouths of the venæ cavæ, *a b*, are not provided with any special and perfect valves, the blood is equally free to regurgitate into them or to pass through the auriculo-ventricular opening, *i*, into the ventricle. But this disadvantageous reflux is guarded against, or is at least rendered more difficult, by some annular muscular fibres of the auricular wall, which surround the apertures of the venæ cavæ. The variously developed (and often cribriform) Eustachian valve of the adult is of little or no use to the inferior cava in this respect. The mode in which the great cardiac vein (*g*, Fig. 90) opens into the auricle prevents the reflux of blood into this vessel, and its Thebesian valve assists to complete this protection against regurgitation.

When the blood passes into the right ventricle, the divisions of the tricuspid valve are apposed to its walls, as indicated by *k l m*, Fig. 90. The fluid is then distributed in the cavity of the ventricle, penetrates between the fleshy columns of the anterior wall, *n*, the septum *o*, and the muscular network, *q r*. The act of systole expels it from all these cavities. But since the tricuspid valve then closes the auriculo-ventricular aperture, and hence shuts off its return into the auricle, there remains but one path of exit; viz., that into the pulmonary artery (*c d*, Fig. 87, p. 174). The path leading to this (*p*, Fig. 90) is distinguished by the uniformity and smoothness of its surface, which greatly facilitates the passage of the blood along this its proper course.

585. The most essential of the phenomena just detailed for the right heart recur in the left one. During diastole, the auricle receives its blood from the two left, *a b*, and the two right, *c d*, pulmonary veins (Fig. 91). The distended auricular appendage, (*m* Fig. 87, p. 174), and the remainder of the auricle, then discharge the greater part, if not the whole, of their contents into the left ventricle; the mitral or bicuspid valve of which (*l m n*, Fig. 91) is in immediate contact with its walls. The general cavity, and the intervals left by the fleshy columns and muscular network, receive the blood at the instant of ventricular diastole. While the auriculo-ventricular valve is shut, the systole again propels

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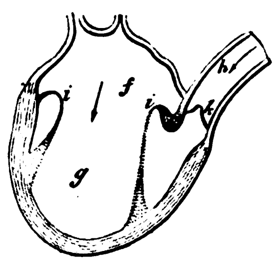
it, by a smooth path, *q*, into the commencement of the aorta (*e*, Fig. 87).

586. The two outlets of each ventricle are provided with valves,—with auriculo-ventricular, and with a system of semilunar valves,—which act in opposite directions. The former (*k l m*, Fig. 90, *l*, *m*, *n*, Fig. 91, p. 178) occupy the points where the auricles open into the ventricles. The semilunar valves or pouches do not lie within the limit of the heart itself, but in the first portion of the pulmonary artery and the aorta. They betray themselves externally by the sinus of Valsalva, which occupies their situation. This is shown for the pulmonary artery by *c*, (Fig. 87, p. 174).

587. The accompanying diagrams (Figs. 92 and 93), each of which represents one half of the heart, may explain the alternate action of these

FIG. 92.

FIG. 93.



two sets of valves. When the ventricle (*b*, Fig. 92) contracts, the corresponding auriculo-ventricular valve, *d d*, is shut, while the stream of blood injected into the arteries in the direction of the arrows tends to press the semilunar valves, *e*, against its walls, and thus opens the outlet. But when the ventricle falls into a state of diastole (*g*, Fig. 93) the auriculo-ventricular valve, *i i*, is opened, in order that the blood may enter from the auricle. And if the blood just impelled into the arterial trunk, *h*, attempts to fall back, it is caught in the pouches, *k*, which thus, like the valves of the absorbents formerly (§ 547) mentioned, exclude the possibility of an injurious regurgitation.

588. In the dead subject, it is evidently impossible to imitate all the changes in form of the living heart; and especially those which accompany its systole. But the valves just mentioned may easily be disposed so that their form may be seen at a glance; and their alternate play may be closely imitated by an artificial and intermittent pressure.

589. The accompanying figure (Fig. 94) shows the upper surface of the ventricles and neighbouring textures in the heart of a strong young man who had hanged himself. The slit auricles are partly removed, partly rolled up for the sake of the view: so that we see only a part of the auricular partition, *e*. The heart is suspended from, and extended

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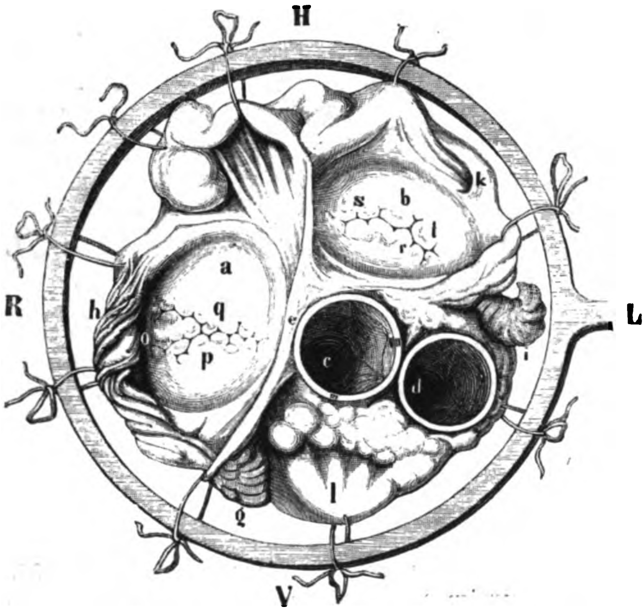
by, a ring; and exhibits that instant of time which corresponds to the act of systole, or in which the auriculo-ventricular valves are shut, while the semilunar valves are open. *R* indicates the right, and *L* the left side of the organ; *V* is the fore, and *H* the hinder part.

FIG. 94.



We may first see how the margins of the tricuspid valve (*a*, Fig. 94) are applied to each other. Here *o* and *p* correspond to the two anterior lobes of this valve (*k* and *l*, Fig. 90, p. 178) and *q* to the internal one (*m*, Fig. 90). The same holds good for the bicuspid valve, *b*, Fig. 94, where *r* is that larger segment which lies before the entrance to the aorta (*l*, Fig. 91), and *s t* is the double and smaller division which occupies the external wall of the organ. These peculiar structures are best shown by pouring in water from the pulmonary artery and aorta, until it reaches to a point in these vessels which is somewhat higher than the region of the auriculo-ventricular valves. But if a part of the valve is ossified, or if one or more of the tendons which pass to it are injured, this accurate occlusion ceases to obtain. Hence it is absent during life, if calcareous masses have been deposited in these structures, or if any other organic faults have implicated these or neighbouring parts.

The semilunar valves of the pulmonary artery, *d*, and of the aorta, *c*, are represented at the instant of the ventricular contraction, when their pouches are in apposition with the arterial walls. The centres of the free margin of all these valves present tubercles, which are distinguished

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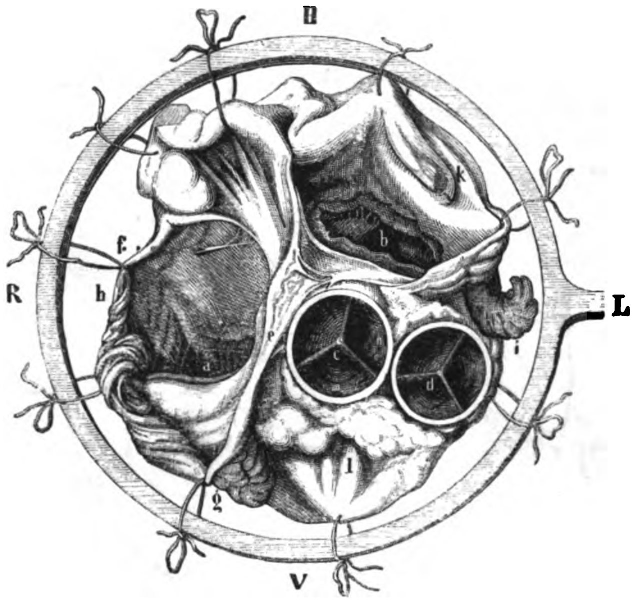
by the names of Morgagni and Arantius in the case of the pulmonary artery and the aorta respectively.

FIG. 95.



590. The diastole of the same heart is represented in Fig. 95. Here the right and left auriculo-ventricular apertures, *a* and *b*, are open. The mitral and tricuspid valves are seen apposed to the ventricular walls. The semilunar valves of the pulmonary artery, *c*, and of the aorta, *d*, were thrown into this state by filling all their pouches with water. Their angular margins are apposed to each other at an angle of 120 degrees; and at the same time the corpora Arantii and Morgagni meet accurately as shown in the figure.

591. Let the right or left ventricle (*a*, Fig. 96) be laid open, and suitably suspended from a ring, *b*; and let a tube, *d*, be tied within the pulmonary artery or aorta. If the ventricle, *f*, be now filled with water, the proper application of pressure to the under part of *f* will shut the auriculo-ventricular valve, and will propel the water into *d*. When the agency of the hand ceases, the water remains in *d* at a point higher than before, since it is prevented from receding by the semilunar valves. A second attempt will drive it still higher. In this way we may obtain an ocular demonstration of the alternate play of the valves, and their influence on the movement of the blood. According to Fick, if tubes be properly tied into one vena cava and the pulmonary artery of a heart, and if it be then placed in water, an alternate pressure upon its cavities will

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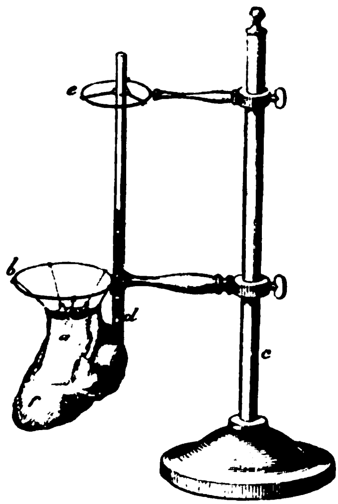
drive the fluid through the right heart in the normal course of circulation.

592. The slightest pressure suffices to close the auriculo-ventricular valves. A very weak contraction of the wall of the ventricle — indeed the mere force with which the blood is expelled from the auricle, and rebounds or is rejected by the elasticity of the ventricular walls — completely suffices for this purpose. The blood is caught behind the membranous parts of the valve, distends them, forces them against each other, and, in this way, completes the occlusion. During this operation the edges of the valve — the forms of which correspond to each other — are, if necessary, rolled up, in order to their still more accurate coaptation.

FIG. 96.

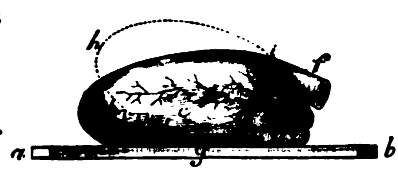


593. The experiments just mentioned, in which satisfactory results have been deduced from the dead heart, indicate that the muscular fibres that penetrate the edges of the valves are not necessary to their closure. And since they chiefly come from the auricles, their activity will occur during the relaxation, and not during the contraction, of the ventricles. Hence we may conjecture that they tend to raise the valves, in order that the blood may be more freely caught behind their membranous portions.

594. The excised and emptied heart of various animals—and especially of young mammalia, of amphibia, and of fishes—will, under favourable circumstances, continue to beat for a long time in the open air. And thus we can immediately investigate all those changes accompanying systole and diastole, which are independent of the attachment, the situation, and the natural contents, of the heart.

595. Fig. 97 exhibits the excised heart of a pregnant rabbit: it is lying on a glass plate, and is seen from the left side. The drawing, executed in light and shade, and which corresponds to the state of relaxation, was taken immediately after the termination of a stroke of the heart. The dotted outline which shows the systole of the ventricles was taken during this period.

FIG. 97.



The left ventricle is indicated by *c*, the left auricle by *e*, its appendage, *d*; the aorta by *f*, and the outline of the contracted ventricles, by *g h i*.

596. Confining our attention to a beat of the heart, such as is meant to be represented by Fig. 97, we shall find that during diastole the ventricle lies at full length, and in spite of its general rounded form is remarkably flattened from above downwards. A powerful systole elevates the extremity which forms its apex to the extent indicated by *g h i*. The whole is at the same time rounded, so that its transverse section undergoes a transition from the previously oval form to a more circular one. But neither by a strong or a weak systole is a truly conical form produced.

In the excised heart of the frog (Fig. 99) this form, however, does appear, although not with mathematical accuracy. The elevation of the heart's apex is here also very distinct. The amount of such elevation depends upon the strength of the contraction, and upon the angle formed by the plane of the transverse fissure with the surface upon which it lies.

597. If the heart be emptied of blood, and the auricles cut away, with even a considerable part of the upper half of the ventricles, still, in spite of this, the apex is often raised during systole. Hence this phenomenon must depend on the arrangement of the muscular fibres. The absence of the muscular masses which lie in the neighbourhood of the transverse fissure, and which give rise to most, if not all, of the ventricular fibres, does not cause it to cease. Sometimes, indeed, the upper segments contract and round themselves imperfectly; or the extreme apex of the large mammalian heart may be bent upon itself in the shape of a hook.

598. If we open the thorax of a rabbit which has been narcotized by æther, we shall find that the different forms taken by its heart during systole and diastole can scarcely be delineated with accuracy. The obstacle lies, not so much in the velocity with which contraction and relaxation follow each other, as in the fact, that the unavoidable irregularity of the heart's action causes it to assume a great variety of shapes during different beats. Hence the slower and more uniform beating of the frog's heart is preferable.

These phenomena are represented in Figs. 98 and 99. They exhibit the heart of a large frog which had been narcotized with æther. At *a b* is the auricle, which is single externally, but is divided internally into two sacs. At *c d* is the transverse fissure of the heart, *e* is the apex of the single ventricle *c d e*, *f* is the bulbus arteriosus, and *g h* the two chief branches of the artery.

Fig. 98 shows the systole of the auricle, and the diastole of the ventricle. The first of these cavities appears narrowed and compressed; while, on the other hand, the latter, *c d e*, is widened and flattened.

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Fig. 99 exhibits the diastole of the distended auricular sac, *a b*, and the systole of the conical ventricle, *c d e*; the margin of which, *c e*, tapers

Fig. 98.

Fig. 99.

away as it descends. The shading of these two figures is made somewhat dark, so as to render these differences more prominent.

599. From his experiments (chiefly on cats), Ludwig [17]) supposes that during systole the ventricles always tend to acquire a conical form; while the forms which the excised heart assumes during diastole vary with the different collateral circumstances.

600. During tranquil respiration, the beating of the human heart may be plainly felt in the space between the fifth and sixth ribs of the left side. In lean persons, or those in whom the heart beats very strongly, the agitation which accompanies the ventricular systole is visible. The cause of the visible stroke of the healthy heart has been greatly disputed; but hitherto without success.

601. We may see by inspecting Fig. 9, which represents the situation of the thoracic and abdominal viscera in the human subject, that a great part of the ventricle, *a*, is in close proximity to the wall of the chest, *δ*, and the diaphragm, *m n o*. Fig. 100 exhibits the thoracic cavity of an eight months' child opened anteriorly. Here, again, we may remark, that the apex of the ventricle *a*, is opposed to the region of the fifth and sixth ribs, and to the diaphragm, *e*. But this part of the thorax is precisely the place where the impulse of the heart is felt during life. An experiment by Kiwisch proves that the impulse of the half towards the apex is also applied to another part of the thoracic parietes. On opening the abdomen of living animals, the stroke of the heart may be felt through the neighbouring portions of the diaphragm.

602. Two collateral circumstances, which are inducible at will, may for the moment prevent the heart's impulse from being felt. If we lean obliquely backwards, and breathe as deeply as possible, while we endeavour to follow the heart's impulse with the hand, we shall find that it gradually becomes more indistinct, and finally altogether disappears. The probable cause of this phenomenon may be explained by Fig. 101. Here the lungs (*b c*) which were altogether collapsed in Fig. 100, have been artificially inflated from the trachea (below *f*). We may notice that a portion of lung (*c*) intervenes between the corresponding parts of the heart and the wall of the chest. But since the bronchial ramifications, which are filled with gases, propagate the concussion but imperfectly, the

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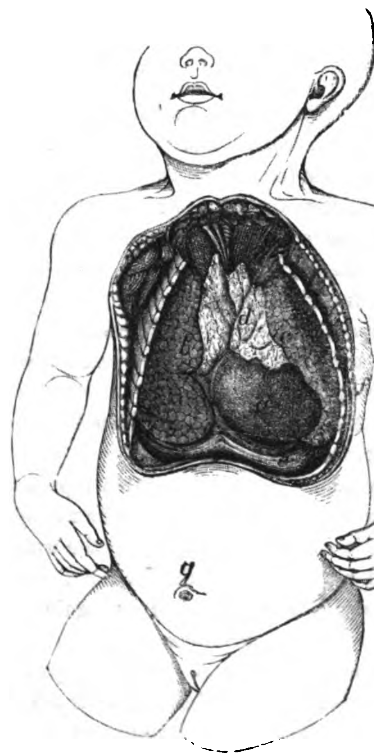
impulse will be less distinct. And if a person turns in bed from the left to the right side, the sensible impulse may likewise disappear. These facts at any rate teach us that the heart, which is inclosed air-tight in the chest, does not under all circumstances press against its wall.

FIG. 100.



603. When a muscle contracts, the length of its fibres diminishes, while their transverse diameter increases in size. And since most of the fibres of the ventricle pass, though by oblique paths, from its base to its apex (from *c* towards *u*, Fig. 87, p. 174), we might expect that its walls would increase in thickness at the instant of contraction. They will therefore be pressed against the neighbouring solid tissues. From this cause Kiwisch deduces the cardiac impulse; and hence, according to him, it disappears after the air-tight thoracic cavity has been opened, because the entering air displaces the heart from its normal neighbouring parts, and especially from the soft intercostal muscles.

604. Since it is at present doubtful whether such a thickening of the cardiac walls could produce the strong impulse, and since at any rate the heart is not immovably fixed (§ 602), the older opinion remains unre-

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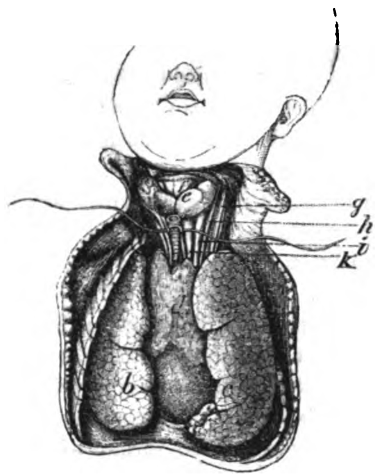
futed—viz., that the heart's stroke is chiefly caused by that elevation of its apex which was previously mentioned. It is perhaps assisted by the

FIG. 101.

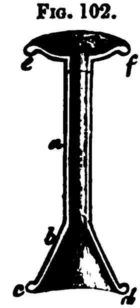


simultaneous filling of the auricles, which changes the heart's centre of gravity; and by the extension of the pulmonary artery and aorta, from which the organ is suspended.

605. On applying the ear to that region of the thorax in which the cardiac impulse is felt, we hear, during each pulsation, a first sound, which is deep and dull, and a second, which is higher, clearer, and of shorter duration.

If the funnel-shaped extremity of a stethoscope—such as is delineated in longitudinal section, in Fig. 102—be pressed against the wall of the thorax, while the ear rests against its flat upper end, we can also perceive these cardiac sounds.

FIG. 102.



606. Experiments made on mammalia show that the first sound of the heart coincides with the contraction of the ventricles, the second with their relaxation. The removal of the walls of the thorax, or the absence of impulse, in no way prevents it. Hence the phenomenon is based upon the alternate conditions of the several parts of the heart itself, and not upon its collateral relations to neighbouring structures.

607. The play of the valves of many hydraulic machines leads to distinct developments of sound. And, remembering that the first sound coincides with the systole, and with the shutting of the auriculo-ventricular valves, while the second concurs with the diastole, or with the closure of the semilunar valves, we may conjecture that the two sounds of the

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heart are valvular, and proceed from vibrations of the stretched and concussed membranes of the valves. The waves of sound propagate themselves very well through solid or liquid substances; while gases oppose great obstacles. Hence the sounds of the heart are less distinctly recognized when the lung, filled with air, projects before the heart during a deep inspiration (§ 602).

608. Many observers have regarded the first sound as merely muscular, *i.e.*, as a phenomenon which accompanies the contraction of the muscular fibres. But the sound of the heart essentially differs from those sounds which are heard during the contraction of the biceps or the abdominal muscles. Besides, it does not increase with the strength of the systole.

609. The whole of the blood which is expelled from the right ventricle proceeds to the lungs, or to a part of the body which lies at some distance from the heart. But the fluid which is propelled by the left ventricle into the aorta exhibits a difference in this respect. A part of it, although proportionately a small one, turns back, as it were, to the heart itself. It enters the mouths of the coronary arteries (*m n*, Fig. 94, p. 181) which lie immediately above the semilunar valves. Since at their commencement these vessels run on the surface of the ventricles, the most powerful systole will not prevent the entry of the blood. According to Kleefeld, if we pierce one coronary artery of a living dog a continual stream of blood issues from it. But it is stronger at every contraction of the ventricle, and slackens at the period of its relaxation. The veins of the heart empty their blood into the right auricle at the time of its diastole.

FIG. 103.

610. If we suppose *a* (Fig. 103) to represent the beginning of the aortic system, each ventricular systole will impel into it a certain quantity of blood. But at the time of diastole this phenomenon ceases. Hence the propulsive force of the heart does not work uninterruptedly; but there is a constant alternation of activity with rest. And since the commencements of the arteries cannot take up all the newly injected blood, the entire column of blood which they contain is propelled onwards a certain distance at the instant of the ventricular contraction.

611. We will first suppose that the arterial walls were quite unyielding, and that *d e g h i* indicated the places where the arterial merged into the capillary system. If a certain quantity of blood were impelled from *a* into *a b c*, an equal quantity of fluid would instantly be expelled from *d e g h i*. Since this would happen before the end of diastole, the column of blood

in the vessel would experience an alternation of movement and rest. And every ventricular systole must necessarily begin a new impulse.

612. But we have already seen (§ 57) that the arterial coats possess a high degree of elasticity. As we shall have to make further use of the arch at *a* (Fig. 103), we may first, for the sake of simplicity, consider the influence exerted by elasticity in connection with the points *k h i*.

613. The systole that expels a certain column of fluid gives rise to a pressure, which first acts on the transverse section *k q*. But since the tension of fluids is propagated equally in all directions, (§ 81) it also acts to an equal extent on the lateral walls, *k m* and *q r*. It thus meets with certain obstacles in two directions, viz., the column of blood already present, in *k q*; and the resistance of the lateral walls, *k m* and *q r*.

If these latter were perfectly inflexible, the pressure could only remove so much from *k q* towards *m r*, and impel so much new fluid, as would correspond to the surplus left over and above the resistance of the column already present, a surplus which we could again represent as a certain amount of opposing pressure (§ 103). But since the arterial coats are elastic, a certain segment immediately undergoes an extension, which extends it, let us suppose, from *k m* to *k l m*. But the dilatation of the transverse diameter, *l s*, leads to an enlargement of capacity in this place. The total quantity of fluid injected is divided. A certain quantity displaces the column of blood already present, and drives it onwards; while another portion is claimed for the dilatation of the arterial tube.

614. If we now suppose the ventricular systole to cease, with it will also cease that pressure, the immediate effects of which have just occupied our attention. The tension which kept the arterial coats extended is now absent. But under such circumstances an elastic body strives to return to its earlier form, and gives back the pressure which it has previously received. And when *k l m* and *q s r* seek to recover their former situation, they press upon the column of blood which they enclose. This might diverge from *m k* in two directions, either towards *a* or towards *h i*. The force which urges it towards *a* acts upon the semilunar valves situate here in the manner depicted at *c* Fig. 95, p. 182. Thus the centric reflux towards the heart is instantly checked. And hence the reaction of *k l m* and *q s r* can only drive the column of blood in the forward or peripheric direction.

615. We see from hence that the elasticity of the arterial walls subserves a double use. It closes the semilunar valves, so as to prevent the reflux of the blood injected by the previous systole, and oblige the diastolic ventricle to derive its new fluid exclusively from the auricle. Besides this it furnishes a specific force of pressure, which is active during the

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relaxation of the ventricle. And thus that which is originally produced by the ventricular systole is subdivided. A certain quantity of it, which is lost for the instant by reason of the extensibility of the arteries, is, as it were, repaid in the subsequent diastole. In this way the column of blood is never absolutely at rest, but is constantly flowing; with a velocity which is only accelerated during the systole of the ventricle, and diminished during its diastole. Hence cutting through the artery of an animal we get a stream of blood, which never completely intermits, but only becomes greater at the time of ventricular contraction. This continual movement of the arterial blood furnishes an uninterrupted stream, which requires a smaller absolute force of pressure.

616. The more exact researches which have been made by Frey[18]) and others, on the waves of the arterial circulation, furnish results that are a great advance upon all the opinions hitherto held on this point. But to investigate even their more important details would lead us too far. Hence we will endeavour to limit ourselves to some of the better known and principal facts.

617. The elastic tissues of the arteries take an angular course, part of them being chiefly in the longitudinal, part in the transverse, direction. The injected fluid will therefore extend these tubes in both directions. Since the structure, the interlacement, and the degree of elasticity, vary in different vessels, the nature and amount of this change will also differ in the several arteries. And, besides this, the resistances which oppose the propulsion of the blood vary with the mode of division, the angles, the number, and the form, of the capillary vessels.

618. While the contraction of the ventricle impels its blood into the commencement of the arterial system (*a*, Fig. 103), a certain quantity of the same fluid flows from its inferior extremities, (*d e g h i*), into the capillary vessels. The former phenomenon leads to waves of dilatation or distension, (*k l m* and *q s r*,) which take a peripheric course; the latter, to waves of constriction or narrowing, (*n o p*), which pass towards the centre. The two kinds of waves tend to defeat each other. But since, during systole, more blood is impelled into, than expelled from, the arterial system, the waves of distension conquer, and take a peripheric course, although diminished in size.

619. On the cessation of the cardiac pressure at the end of the ventricular systole, the elasticity of the elongated and widened artery tends to restore it to its previous size. The continual flow of blood into the capillaries causes waves of narrowing, which take a central course; while the filling of the semilunar pouches produces a very small constricting undulation, which has a peripheric direction. But since all backward course into the heart is almost instantly shut off, the return of the arterial coats to their previous condition must then furnish an undulatory propulsive force, which impels the blood in the peripheric direc-

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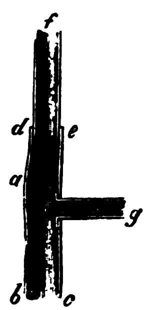
tion. And a complete return to this previous condition can only obtain, when the surplus furnished by systole has been poured into the capillary vessels in the course of diastole.

620. The length of the elastic tubes, the resistance offered by the friction and adhesion of the blood (§ 105), the reflection of undulations, and the other obstacles which are afforded by the division, curvatures, and ramifications of the blood-vessels—the latter, be it remembered, increasing the total size of the channel—all these will gradually lower, and finally annihilate, the heights of the progressive waves of distension shown in the diagram between *k* and *n* (Fig. 103, p. 188). Hence the volumes of the waves must diminish the further they extend into the ramifications. But their lengths are not necessarily altered.

621. Many arteries, such as the carotid of the dog, appear to permit of a greater extension in the longitudinal than in the transverse direction. Hence, during life, elongation probably predominates over dilatation. If such arterial trunks are fixed more loosely in their course than at their extremities, they become curved on the access of the ventricular systole. The dotted line, *a b c* (Fig. 103), seeks to represent this on a magnified scale. And, for the same reason, arteries which take a serpentine course become more curved, as is shown by an imaginary representation at Fig. 104. The ascending aorta (*a*, Fig. 103) tends to become stretched.

FIG. 104.

FIG. 105.



622. The hæmadynamometer (figured at p. 31, Fig. 8), which shows the pressure, tension, or current force of the blood, may be fixed into the arteries in two ways. If we suppose that *a*, Fig. 105, is an artery, the cardiac end of which is at *b c*, its blood will flow in the direction of the arrow. If the extremity, *f*, of the hæmadynamometer be fixed in the portion, *d e*, of the cut artery, the blood will press upon the mercurial column of the manometer. But it is thus prevented from following its usual path. If, on the other hand, the end of the instrument, *g*, be applied laterally, the current of blood can still flow onwards to the ramifications of the arteries. And since the pressure of liquids is pro-

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pagated equally in all directions (§ 81), the manometer united with *g* will give the same pressure which could have been obtained at *f*.

623. The tension of the arterial blood is so considerable, that quicksilver must be used as the indicating fluid of the hæmadynamometer (§ 82). The one column (at *b*, Fig. 8, p. 31) then descends for a certain extent, and the other (*c*), ascends. It does not, however, remain in this state of disturbed equipoise; but oscillates under circumstances chiefly of two kinds. The pressure may be seen to alter under the influence of the stroke of the heart, and of the respiratory movements.

624. The average pressure generally met with in the larger arteries of mammalia amounts to about ·59 to ·63 inches of mercury. This gives from 78·7 to 88·6 inches of water, and 74·8 to 78·7 inches of blood (§ 87). Hales fixed a sufficiently long glass tube into the carotid of the horse, and found that the column of blood ascended more than 78·7 inches before its weight formed a counterpoise to the current force of the blood.

625. Since the influence of the respiratory movements in this experiment is very energetic and striking, it will be next considered. If the animal inspires strongly, the thorax is considerably distended. This increase of space produces a negative pressure. Hence the external pressure of the atmosphere drives in compensating substances wherever it finds them, until its tension is equalled by that of the thorax, and until the rarefaction produced by its dilatation is terminated by the filling of the cavity. In treating of respiration, we shall hereafter find that it is in this way that the air is forced into the lungs. And since the vessels enclosed in the cavity of the thorax are immediately continuous with those exterior to it, their fluid contents must partially follow this draught. Now the arterial blood runs in a peripheric direction from the thorax towards the other parts of the body; while the venous blood and the lymph take exactly the opposite course. Hence the act of inspiration furnishes a pressure, which is opposed to the tension of the arterial blood, as a negative quantity, but which, on the other hand, raises that of the lymph and venous blood, as a positive one. And since expiration produces a diminution in the capacity of the chest,—and hence a positive pressure, which is directed towards the periphery,—it is capable of raising the current force of the arterial blood. These phenomena are most marked in the deeper respiratory movements. In the tranquil respiration of not very excitable animals,—as, for instance, in the healthy horse,—their influence generally disappears.

To take one of the most common instances,—a hæmadynamometer fixed into the carotid of a small dog indicated 5·51 inches as the lowest estimate during inspiration, and 8·35 as the highest during expiration. Hence the latter was half as much again as the former.

626. Ludwig and Sprengler fixed a hæmadynamometer into the carotid

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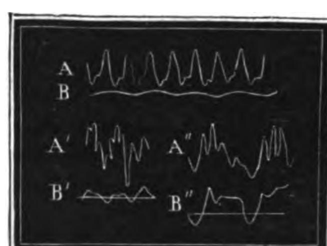
of a horse, and a second instrument into the maxillary or the posterior external metatarsal artery. And by following the simultaneous play of the two manometers, they found that the deviations dependent upon deep respiratory movements were less in the smaller and more remote arteries. For instance, the carotid gave 5·04 and 6·61 inches: the maxillary artery 4·88 and 5·2. The carotid of a second horse gave 3·54 and 6·54; the metatarsal artery 5·43 to 5·51. We shall hereafter see that in the smallest arteries and the capillaries the variations produced by respiration can no longer be recognized.

627. If the phenomena be investigated under the most favourable circumstances (such as will shortly be mentioned) it will be found that, during strong expiration, the mercurial column is suddenly elevated. It rises with every systole of the left ventricle, recedes somewhat during diastole, rises yet higher during the second systole, and so on until it reaches its greatest expiratory elevation. During the long subsequent inspiration it descends uniformly; or, at any rate its impulses are rare and inconsiderable.

628. Thus, for instance, in the dog mentioned above, the elevation of the index mercurial column produced by contraction of the ventricle was from ·04 to ·055 inches. Hence (§ 86) the act of systole raised the pressure from ·08 to ·11 inches of quicksilver. But under other circumstances it may either be less than this; or, *vice versâ*, may rise to ·39 and even more.

629. Ludwig [19]) so arranged his apparatus that the ascending and descending quicksilver columns of the manometer set in motion a float which carried a pencil. This marked out the variations on a sheet of paper, which again was coiled around a cylinder that was made to revolve uniformly upon its upright axis by clock-work in a known time. In this way he obtained graphic representations, such as are represented by A, A′, A″ (Fig. 106). They not only permanently expressed the nature and amount of the variations, but also accurately determined the time which they occupied. He also introduced into the chest, through a slit in its softer textures, a bladder fastened air-tight to a tube and filled with water. This he connected with a second and similarly arranged hæmadynamometer; he thus obtained a new series of lines, B′, B″, B″, which gave at least a tolerable approximation to the variations of pressure occurring in the thoracic cavity.

FIG. 106.



630. This ingenious method of experimenting confirmed the fact previously mentioned (§ 625) that the tranquil respiration of a not very

excitable animal, such as the horse,—which has also but very few (35 to 45) beats of the heart in a minute,—does not materially influence the force of the arterial current. The neighbouring hills and valleys of the blood-curve (A, Fig. 106) for the most part correspond with each other; although the respiratory curve (B), exhibits distinct but small elevations and depressions.

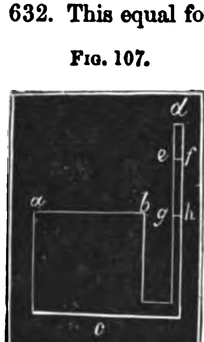
The influence of strong expiration is marked by an increase in the systolic rise of pressure, and, *vice versâ*, by a diminution in its diastolic fall. The correctness of this conclusion may often be remarked in the ordinary series of experiments made on the dog. Here it sometimes happens that the indicating column does not recede during diastole, but either stands still, or even rises. A graphic representation of this, as seen in the carotid artery of the dog, is given by A′ and B′, (Fig. 106).

Conversely, the act of inspiration will counteract the systolic rise, and assist the diastolic fall. Hence the blood-curve may exhibit a fall, which is either continual and uninterrupted, or is mixed with very trifling single elevations. A″ and B″ represent this from the carotid of the horse.

631. The large arteries of the greatest and the smallest dog betray no essential and constant differences by the hæmadynamometer. The act of expiration can force the mercurial column just as high in the smallest lap-dog as in the horse. If we attempt to introduce the manometer into the carotid of the rabbit or guinea-pig, we get, as a rule, a somewhat lower average of current force. Thus, for instance, we generally find only 4·13 to 5·31 inches. It is possible that a small part of this diminution is real and essential. But it is obvious that there are other obstacles, upon which the smallness of this estimate may equally depend—such as the fineness of the arteries, the use of very small and terminal tubes which is thus necessitated, the facility with which small plugs of coagulum are produced, and the proportionally large quantity of blood that is lost by the animal.

632. This equal force of the arterial current in the smallest dog and the largest horse does not contradict the other phenomena of the circulation. If we suppose that the apparatus at Fig. 107 is filled with fluid up to $a\,b\,g\,h$, and that any force equal to the pressure of the column $e\,g$ (§ 102) operates from $g\,h$, the quantity of fluid poured out in a given unit of time will essentially depend upon the diameter of the orifice of exit, $a\,b$ (§ 81). Other circumstances being equal, the two vary mutually with each other. But the hæmadynamometer only shows the amount of pressure $e\,g$.

Fig. 107.



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The size of the cavity of the left ventricle, upon which the quantity of fluid then at its disposal depends, and the orifice of exit into the aorta,—which corresponds to $a\,b$,—are arranged conformably to the other circumstances of the circulation. Hence the height of the pressure $e\,g$ may remain the same, without any prejudice to the quantity poured out—a quantity which corresponds to the size of the body, and to the other arrangements of the circulation.

633. If a healthy heart be separated as much as possible from its fat, and if the free walls of its right and left ventricle be cut away from the partition common to both, it will be found that the portion belonging to the left ventricle has nearly twice the weight and volume of that which corresponds to the right one. And regarding the ventricles as two sacs united to each other, with a common partition which is divided between them in the same proportion, it will follow that the right possesses only half as much muscle as the left one. Now we have already seen that the capacity of the two ventricular cavities is probably equal during life. Their apertures of exit into the aorta and pulmonary artery also exhibit nearly the same size. And if, under these circumstances, we regard the heights of pressure as dependent upon the total mass of muscle, we may conjecture, that the mercurial column of an hæmadynamometer inserted into the commencement of the aorta would rise twice as high as that of a similar instrument placed in the trunk of the pulmonary artery.

Under abnormal circumstances it sometimes happens that the heart of a new-born infant or animal is protruded, and hangs free, from a fissure in the apposed wall of the thorax. This malformation, which is known by the name of ectopia of the heart, depends upon an arrest of the usual development. There is a time in the evolution of the embryo at which such a condition of the heart is normal.

Hering [20]) made use of the rare opportunity afforded by such a deviation in a living calf, as a means of direct research into the pressure of the heart. He introduced a glass tube of sufficient length into the right, a second into the left, ventricle, and a third into the right auricle. The blood of course rose just so far as the hydrostatic pressure of the liquid column could be sustained by the force of the corresponding part of the heart. The minimum of the right ventricle was 20·36 inches; that of the left 33·86. The corresponding maxima were 23·7 and 38·55. Hence the pressure exercised by the right ventricle has to that of the left the proportion of 1 to 1·7. The right auricle gave a result of 7·91, or about one-third the pressure of the right ventricle. The contraction of each ventricle drove its column of blood from 1·7 to 2·24 inches upwards, and that of the right auricle from ·59 to 1·14 inches.

Now, 20·36 inches of blood correspond to 1·7, and 38·55 to 3, of mercurial pressure. Hence we see that these amounts are considerably smaller than those obtained by the hæmadynamometer in the larger

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arteries (§ 624). Although the calf examined was only eleven days old, still it is improbable that the difference can be explained by the tender age of the animal. We may rather conjecture, that the abnormal circumstances of the malformation, and especially the exposed situation of the heart outside the chest, were the cause of the small absolute estimates obtained in this remarkable observation.

634. Hitherto we have only regarded the arteries as elastic tubes. The numerous elastic fibres which occupy their coats (Tab. III. Figs. XLII., XLIV.),—and probably their more uniform fenestrated membranes (Tab. III. Fig. XLIII.) — are the agents of this property so important to the circulation. Besides this, experiment teaches that the arteries possess a certain capacity of contraction. If the shocks of the electro-magnetic apparatus (§ 248) be allowed to operate continuously upon an artery, it often becomes constricted in the neighbourhood of the conducting wires, and only returns to its previous cylindrical condition after a long period of rest.

635. On laying bare the carotid of a living animal, we see no phenomenon which would in any way prove a capacity of instantaneous contraction. No trace of vermicular contraction can be remarked. No part of its diameter alters with sufficient rapidity to allow of the change being followed by the naked eye. And generally (if not always), even an artificial mechanical irritation has no effect.

636. If a large arterial branch be divided, either during the amputation of a limb, or by any other kind of wound, it retracts in the longitudinal direction. Some might attempt to explain this fact as being a mere result of the elasticity of its coats. But the transverse diameter is often considerably diminished at the same time. And this phenomenon cannot be based upon mere want of stretching, still less upon elasticity, since the cavities of emptied arteries remain open. Hence it is probable that this result is due to their capacity of contraction. The application of cold water facilitates the closure of the severed opening; and if this be not exclusively dependent on its furthering coagulation, it will additionally argue the vital character of the contraction which here occurs so energetically in the arterial coats.

637. The injection of a recently killed animal frequently fails, on account of many of the arteries presenting scarcely any cavity. But if the experiment be repeated on the following day, the fluid easily penetrates their reopened cavities. Two interpretations of this phenomenon may be given. The cessation of circulation and respiration after death has removed a certain tension, which formerly stretched out the arterial coats; and hence they are correspondingly narrowed. But since the closure of their calibre cannot depend upon this phenomenon alone, it is possible that the process is completed by a spasm of those tissues which are capable of vital contraction. The second explanation may be found

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in the circumstances of the *rigor mortis.* This consists in a physical change of the contractile tissues: which show, as it were, the first step towards putrefaction by a contraction; but, under the influence of progressing decomposition, are subsequently again relaxed.

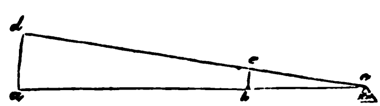
638. Many facts which we shall hereafter learn from a study of the nervous functions indicate that the living arteries are capable of gradually altering their diameter under various circumstances. But it has hitherto been found impossible to explain with sufficient clearness the causes, or even the external phenomena, of this change.

639. The pulse is that sensible series of effects produced by the action of the ventricle upon the arteries. The changes thus brought under notice may be demonstrated by sight, hearing, and touch.

640. The beating of arteries which lie immediately under the skin,—or, what is more usual, only in its neighbourhood—may frequently be seen. The slight extension and exaggeration of their curves (§ 621) thus produced are more prominent than their dilatation.

641. If the hollow of the knee of one leg be allowed to rest upon the knee of the other one, it may be remarked that the point of the suspended foot moves visibly up and down at each beat of the pulse. The result is greater in this point than it is on the artery itself, as may be explained by a reference to the annexed diagram (Fig. 108.) Suppose *a b c* to be a

FIG. 108.



lever, movable at *c*, the point *a* will move through the larger arc, *a d*, while *b* is only moved from *b* to *e*. If we substitute the popliteal artery in the hollow of the knee for *b*, while *a* represents the point of the foot, the latter will also exhibit a more considerable range, *a d*.

642. If the carotid artery of a living mammal be laid bare, the sounds of its heart may be plainly heard by means of a suitable stethoscope (§ 605) laid upon the vessel. Attempts have also been frequently made to ascertain the diseased conditions of the arterial coats by means of a similar method of research.

643. The ordinary medical examination of the pulse depends upon the evidence afforded by the sense of touch. For this purpose we select the radial artery, which lies immediately under the skin: or, less frequently, we choose other arteries which are similarly placed in this respect, such as the temporal, carotid, femoral, or popliteal vessel. We thus feel that impulse and alteration of position which originally come from the contraction of the ventricle.

644. Many of the kinds of pulse distinguished in pathology are based

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upon direct and accurate observation. But others are mere subtle distinctions, which have been much favoured by the scholastic direction given to scientific research in previous centuries. Still it must be admitted that our present knowledge of the phenomena of circulation is no way sufficient to a satisfactory explanation of all the varieties of pulse. The amount of pressure exerted by the ventricular contraction—the quantity of fluid which is injected on one side, and streams into the capillaries on the other — the character of the vascular tubes which occupy the intervening space — the assisting or opposing influence of the respiratory movements—the time which is required for the several changes — all these together conduce to that general result which we designate by the name of the pulse.

645. If the arteries formed completely rigid tubes, the stroke of the heart would be propagated in an extremely short time to the most distant of these vessels. The waves which result from the elasticity of their walls demand for their diffusion a larger space of time. Since in the adult man the time between any two beats of the heart amounts to less than a second, this difference will but give us a minimum of the time. And although on theoretical grounds it might be expected that the arteries more distant from the heart would beat somewhat later than those which commence the arterial system, it will not surprise us to find that, in ordinary observations, this small difference of time is not detected. If we compare the carotid with the peroneal artery, which runs in the neighbourhood of the outer ankle, in a few favourable instances we may remark a small difference of time, which amounts to about 1-6th to 1-12th of a second. It is obvious that the amount of this difference will also vary with the condition of the arterial coats, and with other collateral circumstances.

646. Under normal circumstances, the impulsive movement of the blood decreases, the further we proceed towards the finer arterial ramifications, and the closer we approach to the capillaries. We shall hereafter see that a pulsatory movement is only found in the capillaries under certain exceptional circumstances.

647. The larger arterial trunks sometimes unite by cross branches or anastomoses. Now and then they exhibit a dense compressed network, a "*rete mirabile*" as it is called. But with these unusual exceptions, the general character of the arterial system is to extend by continual and repeated bifurcation. The subordinate twigs are thus continually diminished in size, until at last they gradually merge into the capillary vessels, which can only be recognized under considerable magnifying powers.

648. If an arterial trunk (Fig. 109) divides into two subordinate branches, *b* and *c*, the rule generally holds good, that the sum of the transverse sections, *d e* and *f g*, of the two new ramifications, *b* and *c*,

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is greater than the transverse section, $h\,i$, of the main trunk, a. Hence the channel is gradually widened. Still we meet with some constant exceptions to this rule. Thus, supposing b and c to be the two common iliac arteries of a man, $d\,e + f\,g$ will be smaller than $h\,i$, the termination of the abdominal aorta. Anastomosing branches may give rise to similar differences. Such a dilatation of the channel will render the course of the blood slower; while, *vice versâ*, constriction will accelerate it (§ 106).

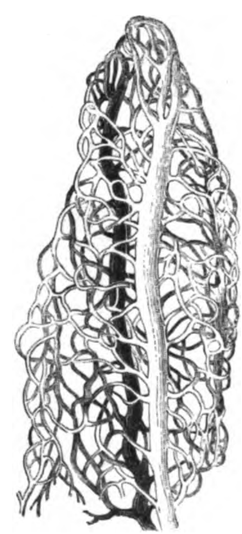
FIG. 109.

649. If we trace the structure of the walls of the arteries from the commencement to the termination of the arterial system, we shall find that the tissues which form these tunics undergo a gradual degradation. The aorta has in its exterior very strong elastic fibres (Tab. III. Fig. XLII.). As we proceed from without inwards, we come upon finer fibres, which are either free, or are apposed to uniform and fenestrated membranes (Tab. III. Figs. XLIII. XLIV.). A somewhat similar degradation is repeated in the smaller arterial ramifications. Hence the elasticity alters as we approach the periphery. Finally in the capillary vessels all elastic reactions disappear, and with them, we lose all the elastic fibres. Here nuclei, arranged partly lengthwise, partly crosswise, surround a transparent inner membrane.

650. In the arteries bifurcation is the rule, and reticulation the exception. But in the capillaries precisely the reverse holds good. Thus, for instance, in the tactile papillæ of the corium, we find that every smallest artery (Fig. 110) passes into the smallest vein by means of a simple arched loop. But in most other structures the connection is accomplished by nets of various forms.

FIG. 110.

FIG. 111.



This may be represented by Fig. 111, which is a diagram of the distribution of the vessels in the interior of the villi of the small intestine. The small artery (which is represented transparent) ascends on the one side: while one or more dark veins descend on the other. A rich network of capillaries intervenes between the two.

The capillary vessels often exhibit such peculiar forms, that an anatomist can at once state the part from which they have been taken. This is shown by Figs. 110 and 111; and may be confirmed by Figs. 112 and

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113. Of these latter, Fig. 112 represents the capillaries of the human mesentery, and Fig. 113 those of the dried lung. It may be seen that these varieties of form are intimately connected with an alteration in the

FIG. 112.

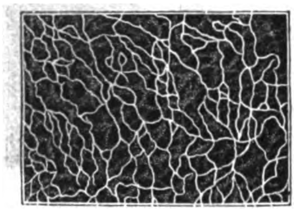
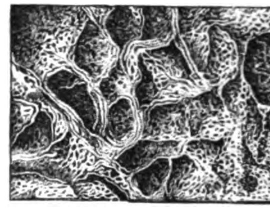


FIG. 113.

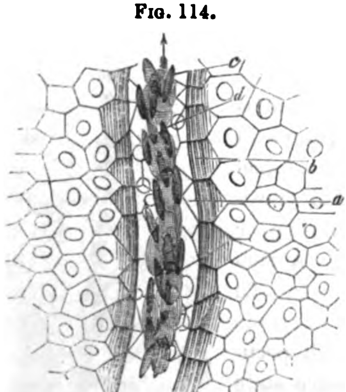


size, shape, and course of the capillary vessels; and of the meshes which intervene between them. Hence they will exercise an important influence upon the quantity of blood which they contain, and the hydraulic relations of this fluid.

651. The circulation in the capillaries and smaller arteries and veins of many transparent parts may be seen under the microscope. Such are the wings of the bat; the mesentery of small animals; the web of the foot, the lungs, and the extended tongue, of the frog; the tail of the triton and salamander; the gills and tail of the larvæ of the reptiles just mentioned; and many parts of the embryonal fish. We are thus able to see much which either does not occur in the larger vessels, or which, at any rate, can only be deduced in a very roundabout way from hydraulic rules and physiological experiments.

652. The use of the microscope necessary to these experiments may mislead the beginner in a twofold way. Let Fig. 114 represent a part of the web of the frog's foot, the pavement epithelial cells of which immediately strike the eye, and let *b* be the limit of the blood-vessel, in which the stream of fluid takes the course of the arrow. If the observation be made under a simple microscope no correction is required, since there is here no reversal of the image. But if, on the contrary, the compound microscope be made use of, we must not forget that this instrument inverts the images. Hence, when the stream of blood appears to be flowing upwards, or in the direction of the arrow (Fig. 114), it is in fact running downwards. And if we

FIG. 114.



are attempting to determine whether a particular vessel be an artery or a vein, this circumstance will have a very essential significance.

653. The velocity may also mislead us. If the same vessel be looked at with different magnifying powers, it will be found that the apparent velocity of the blood's course increases with each of these. Thus, for instance, with a linear magnifying power of 54 times, we can see the passage of the several blood-corpuscles. Under a power of 107 diameters they pass off more rapidly. And under one of 255 the whole moves so quickly that one can only see red rippling streaks, without being able to recognize their individual constituents.

These phenomena are at once explained by considering what are the relative circumstances by means of which we estimate the velocity of a movement. If a body (*a*, Fig. 115) passes through the linear distance,

FIG. 115.

a b, in one second, it must have a velocity ten times as great in order to pass through the path, *a c*, which is ten times as long, in the same space of time. But if we looked at *a b* under a tenfold magnifying power, *a* would appear to pass through the ten times multiplied space, *a c*, in one second, while, in point of fact, it would only be passing from *a* to *b*. Hence its apparent velocity has been ten times multiplied. A magnifying power of 54 diameters would therefore increase it 54 times: and one of 255 diameters 255 times. In one word, the velocity of a movement, seen under the microscope, has the same proportion to the velocity really existing, as the length of the microscopic image has to the real length of the object. That is, it varies directly as the linear magnifying power itself.

654. We shall hereafter find that in the capillaries the blood streams so slowly, that it is only with difficulty that we could follow its progress with the naked eye. The cause of this slowness depends chiefly on the widening of its general channel (§ 106). Those resistances of friction and adhesion which the finer capillaries offer, may also assist in this diminution of velocity (§ 107). But they contribute far less than the increase in the capacity of these canals, which are always filled with blood.

655. In the normal condition, the impulses caused by the several acts of ventricular contraction can no longer be recognized in the capillaries. The blood flows uniformly, without any pulsation. But if the beats of the dying heart follow each other with insufficient frequency, or if the circulation of a capillary, which had previously stopped, recommences,

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the column of blood not unfrequently exhibits a very irregular movement. It presses forward for a certain distance, to rest there, or even to undergo a partial return. This alternation may be frequently repeated in a short space of time.

656. When isolated capillaries of the frog's web are examined under moderate magnifying powers, we remark a colourless streak (*a*, Fig. 114) on the interior wall, *b*, of the tube. The main current of blood-corpuscles, on which the red colour of the blood chiefly depends, runs in the middle, *c*. It now and then happens that a few blood-corpuscles stray into the colourless layer for what is rarely more than a short period. The globular, colourless, and granular lymph-corpuscles of the blood, *d*, Fig. 114, (Tab. II. Fig. XXIII. *c*) are frequently seen rolling slowly along it.

657. The transmission of a fluid through very small tubes gives rise to the production of a peripheric and slow-flowing layer, which has been designated by the name of the immovable stratum. Its occurrence depends upon the diameter and adhesive properties of the tube. This explains why it is larger in some, and smaller in other, capillaries; and why, in many, it is often absent. The cohesion of the *liquor sanguinis* or fluid part, the velocity of the circulation, the quantity and bulk of the corpuscles already present, the temperature of the tissues, and many other circumstances as yet little known, are capable of exerting a visible influence on the thickness of this immovable layer.

658. Since the red colour chiefly depends upon the blood-corpuscles (*c*, Fig. 114), a red median streak, and two colourless lateral margins, may be remarked in all capillaries, the circulation of which corresponds with the above representation. But if a part of the frog's web be burnt with a red-hot iron, or exposed to any other excitant of inflammation, the circulation within a certain distance comes to a stand still. This change is gradually induced. In the few moments which immediately precede it, a large quantity of liquor sanguinis is impelled through the canal, while the blood-corpuscles are retained in continually increasing numbers: so as not only to fill the central space (*c*, Fig. 114) but also the lateral streaks (*a*), which formerly belonged to the immovable layer. Thus we have now a broader red vessel, although its diameter has undergone no real increase. This circumstance has often led to the erroneous supposition, that the capillary vessels are really dilated at the beginning of the inflammatory obstruction.

659. Some of the capillaries of the frog are so small that the comparatively large blood-corpuscles can only pass through them with difficulty. Hence they always contain considerable quantities of colourless liquor sanguinis. They may also easily escape the view at an instant when they are not transmitting any blood-corpuscles. But they do not essentially differ from the others; and hence the special name of serous vessels given them by many observers is inaccurate.

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660. Causes apparently insignificant are capable of throwing the capillary circulation into disorder. If the web of the frog's foot be overstretched, we not unfrequently find that the movement of the blood in most of the microscopic vessels soon comes to a standstill. The use of ice or boiling-water, of æther, alcohol, acids, alkalies, and many saline solutions, may produce similar disturbances. But on the other hand, we may pass many hundred shocks of the magneto-electric machine through the caudal fin of the lamprey, without any visible alteration in the circulation of its capillary vessels.

661. During the first stage of obstruction in a capillary vessel, the quantity of blood-corpuscles gains at the expense of the liquor sanguinis (§ 658). The entire column then either rests, or moves by fits, here and there. Sometimes it is impelled with a violent jerk into a neighbouring vessel, and the obstruction is suddenly removed. In other instances, the collection of blood-corpuscles continues for a longer time. Those which impinge directly upon vessels possessing the normal current of blood are at first shaken by this. They next vibrate here and there until carried away by the neighbouring current. If this allows more fluid to penetrate the column of obstructing blood, the process is repeated one or more times, until finally, the transit of the fluid is so far restored, as that it at once drives the remainder through the capillary vessel.

662. Some of the blood-corpuscles which have strayed into the immovable layer leave it again after a short stay. Others remain here quietly for some time, or wander slowly onward with many oscillations until finally they again light upon the main current. If a blood-corpuscle occupies the diverging path which leads to two capillaries, it not unfrequently moves to and fro for some time before it proceeds onwards in either.

663. That change in the colour of the skin which is excited by mental emotions plainly shows that the capillary circulation is capable of altering in a few seconds under the influence of the nervous system; to which an important influence upon the walls of the capillaries is therefore generally ascribed. But hitherto no physiological experiments have succeeded in explaining the phenomena which cause this change, or have even been able to produce definite variations of diameter in the capillaries of reptiles and fishes. The use of heat, cold, or different chemical reagents only leads to results which are not trustworthy; and the application of electricity, or direct irritation of the nerves, has no visible effect whatever. It is probable that the contractility of the capillary walls is governed by peculiar laws.

664. The arteries pass into the capillaries by continual ramification and diminution. And conversely, the trunks of veins collect themselves together. The most delicate venous twigs connected with the

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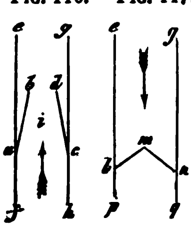
capillaries unite to form larger ones, and these again to construct still larger branches, until they finally result in the trunks of the vena cava, the cardiac, and the pulmonary, veins. The breadth of the venous channel therefore diminishes from the capillary vessels towards the heart. And hence—apart from all other circumstances—the movement which is impressed upon the contained blood will be proportionately quickened.

665. In most parts of the body we find many venous trunks for one artery. The older anatomists believed that the entire venous system occupied from 2¼ to 4 times the space taken up by that of the arteries. So that even without that diminution of pressure to which we shall immediately advert, the venous blood must flow more slowly than the arterial, on account of the difference in the size of its channel.

666. There remain two other peculiarities distinguishing the veins from the arteries. The veins more frequently unite by large anastomosing branches. And besides this, most of them possess valves, which are placed, partly in the course of their trunks, but chiefly where these receive their branches. Both of these arrangements assist to obviate the disturbances which frequently threaten the venous blood.

667. We shall hereafter see that the current force of the venous blood is considerably less than that of the arterial. Hence an external pressure may inflict more injury upon it; especially since its slow propulsion renders it more liable to disturbances. But the anastomoses lead off the stream towards other conduits, which are for the time more favourably placed; or tend to equalize the oscillating velocities and pressures. While on the other hand, the valves, which in all essential points are arranged like those of the absorbents, prevent that prejudicial reflux which external pressure would otherwise induce. If the current of blood takes its normal and centripetal path, as shown by the arrow at Fig. 116, the pouches *a b* and *c d* on the cardiac aspect of the valves are pressed against the walls of the vein *e f* and *g h*, and the aperture *i* is thrown open as widely as possible. But if the blood attempts to sink back in the centrifugal direction, they shut as in *l m n*, Fig. 117. Thus the mechanical advantages referred to in the absorbents are repeated in the veins.

FIG. 116. FIG. 117.



668. Since the blood which returns from the feet, the arms, the belly, and part of the chest, necessarily flows from below upwards, the valves have been frequently supposed to prevent the reflux producible by gravity. But without regarding any of the physical circumstances which contradict this opinion, the example of the jugular vein will suffice to teach us that the application of these valves is based upon

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other causes. The blood of the jugular veins flows from above downwards: but in spite of this they present valves, the cavities of which look downwards, or towards the heart.

669. The muscles, which become shorter and thicker at the instant of their contraction, are capable of compressing the veins; the contents of which, as they possess a small current force, therefore only offer a small resistance. If no valves were present, the fluid would evade this pressure in both the peripheric and central directions. But since the valves always prevent peripheric reflux, muscular contraction is enabled to support the venous circulation, and, in any case, is prevented from materially injuring it.

670. In order that the respiratory movements should further the venous circulation, they must also be assisted by the action of the valves. We have seen (§ 559) that inspiration draws venous blood into the chest, or centripetally; and that expiration can either expel it centrifugally, or can at any rate prevent it from so easily entering this cavity. But all useless reflux is rendered impossible by the valves.

671. In the smallest arterial branches and capillaries, the pressure exerted by the left ventricle of the heart is for the most part lost. There remains but a proportionally small residue, which tends to impel the venous blood from the capillaries towards the heart, or in the central direction, and which forms what is called the *vis-à-tergo* of the venous circulation. Inspiration—or, as we may call it, aspiration—will assist this direction of tension; while the positive pressure of expiration will oppose it (§ 625).

672. On comparing the external jugular vein with the carotid artery, we find that the estimates obtained by the hæmadynamometer may be 10, 15, or even more than 70, times greater for the latter than the former. The carotid of the dog gives an ordinary height of 5·9 inches of quicksilver, but the external jugular vein only from ·08 to ·59 inches. The carotid of a rabbit gave 4·09 inches; its external jugular vein only ·28. These smaller amounts of pressure in the venous blood often oblige us to use an index column of water instead of mercury, in order to obtain more noticeable results (§ 86).

673. The resistances which consume the greater part of the heart's force are due to the subdivided channels of the arteries, and the various networks of the capillaries. But since these causes vary with the differences in the several organs, it is evident that the value of the *vis-à-tergo* will vary in the different veins. Thus, for instance, according to Ludwig and Mogk, the jugular vein of the dog gives ·08 to ·52 inches of mercury, the brachial vein ·49 to ·6, and the femoral ·43 to ·93. And if the neighbouring muscles contract, so as to add the effect of an extraneous pressure, the tension visibly rises.

674. Since, in the smaller arteries, the jerking movement of the blood

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ceases (§ 655), the column of the hæmadynamometer exhibits no pulsatory rise and fall, as long as it merely indicates the *vis-à-tergo*. But deep respiratory movements easily produce an alternate play of the indicating fluid. The mercury of the longer limb (*c*, Fig. 8) of the hæmadynamometer descends during inspiration, and rises under the influence of expiration.

675. This forward and backward course of the blood may be seen without any special preparation in the denuded jugular vein of the rabbit. If an hæmadynamometer be fixed into the centripetal end of a dog's jugular vein, it not unfrequently happens that a deep inspiration exhibits a negative pressure of 1·77 to 3·54 inches; while, on the other hand, a strong expiration shows a positive pressure of 1·97 to 4·72. In the veins of the extremities these differences usually disappear. At most, they only occur exceptionally, and in small quantity. The alteration in the index column rarely amounts to a height of ·39 inches.

676. It is obvious that a small excess of pressure in the blood of the vena cava will suffice to impel the whole mass of this fluid into the relaxed right auricle. It was only necessary that nature should adjust the left ventricle, so that all the force it furnished should not be lost before the completion of the systemic circulation. Any stronger and superfluous tension of the venous blood would have been an useless expenditure of force.

677. But the economy which obtains here as elsewhere, involves many perils. The small resistance of the venous blood often allows external and collateral circumstances to act very injuriously. The different muscular movements, and the various phenomena of respiration, may alter and disturb the stream of blood of particular parts. And although the anastomoses and the valves frequently come to the rescue (§ 667), still, any unusual disturbances which may occur often find a fruitful field for their operation. Particular portions of the veins of the rectum, the thigh, or more rarely of other parts of the body, become dilated; so as to form what are called "varices," or, when occurring in the neighbourhood of the arms, "hæmorrhoids." And it not unfrequently happens, that a large or small series of venous trunks becomes occluded, so that the circulation is forced to proceed by other collateral channels. Calcareous masses are sometimes deposited in the obstructed and coagulated blood. While, on the other hand, the arteries at most only ossify in their coats. Calcareous deposits scarcely ever occur in their contents.

678. We have seen (§ 649) that the elasticity of the arteries diminishes in their smallest branches. And the capillaries are quite devoid of that alternate constriction and dilatation which was noticed in the larger arteries. Apart from the influence of respiration (§ 674), a denuded vein also exhibits no trace of pulsation; but either remains altogether unaltered,

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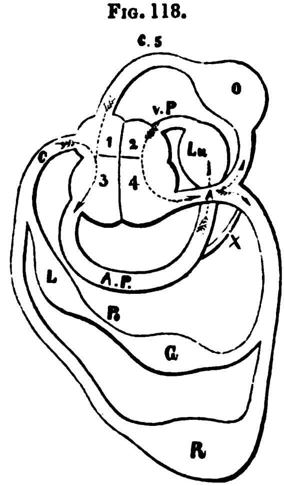
or contracts under the influence of the air so slowly, that the naked eye is unable to follow its gradual changes of diameter.

679. While the elastic arteries remain open after being cut across, the veins, under similar circumstances, collapse. Thus they are only enabled to maintain their cylindrical form against the pressure of the atmosphere by means of the resistance of their contents. Their great extensibility is therefore intimately connected with their small elasticity. Even in the dead body, we may convince ourselves that the veins dilate considerably under suitable force. And, under suitable circumstances, this change also occurs in the living subject. We may daily remark how greatly the size and repletion of the veins of the hand alter according to the various circumstances of the circulation. The influence of respiration, which operates so powerfully upon the jugular vein, leads to similar changes. From this cause the external jugular of a living dog offered a variation of from 1-15th to 1-10th of the entire cubic capacity possessed by the cylinder of vessel submitted to examination. While, on the other hand, the deviation of the carotid artery under similar circumstances amounted to only 1-22nd.

680. It can scarcely be doubted that the walls of the veins possess a certain degree of contractility. But even the shocks of the electro-magnetic machine frequently fail to reproduce the results seen in the arteries (§ 634). And during life, no vermicular movements occur. Nor is there any rapid, instantaneous, and rhythmical alteration of their diameter.

681. Let us suppose 1 and 2, Fig. 118, to represent the right and left auricle, and 3 and 4 the right and left ventricle; the blood which flows into the pulmonary artery *A P* will pass into the capillary network of the organs of respiration *L u*, to return subsequently through the pulmonary veins *V P*, to the left auricle, 2. A blood-corpuscle which enters the aorta *A*, and passes hence to the neck and head, will penetrate the capillaries *O*, in order to gain the superior cava *C* 5. The same process is repeated in most of the remaining systemic arteries, which empty themselves into the inferior cava *C*, through the capillaries *R* and the corresponding systemic veins. In all these instances, the fluid only requires to pass through a single system of capillary vessels, *L u*, *O*, or *R*, in order to pass from the

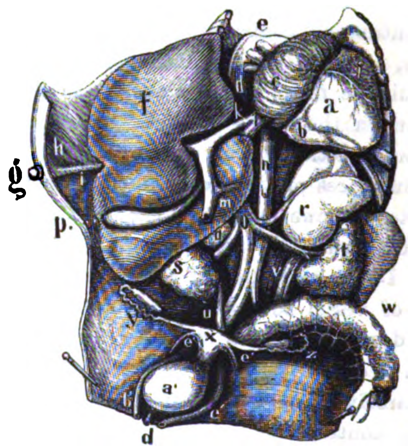
FIG. 118.



arteries into the veins, or from the ventricle, 3 or 4, into the auricle 1 or 2 (§ 574) which lies diagonally opposed to it.

The circumstances of the portal circulation are different. The portal vein (*m*, Fig. 119) receives the veins of the stomach, *q r* (Fig. 9, p. 34),

FIG. 119.



of the small and large intestines, *s t u v* (Fig. 9), of the spleen *g*, and the pancreas, *p q* (Fig. 75, p. 132), and finally those of the gall-bladder, *p* (Fig. 119). It then ramifies in the liver *f* in the same way as an artery, and becomes continuous with the capillary vessels of this organ, which is at the same time nourished by the hepatic artery. The capillaries of the liver subsequently unite with the hepatic veins, and these with the anterior or upper part of the inferior cava, *l* (Fig. 119). The blood which returns from the legs, and ascends in the inferior vena cava *o*, runs behind the liver, to flow immediately into the right auricle. On the other hand, the blood which enters the viscera above named must first run through their capillaries, and must then pass by the roots, stem, and ramifications of the portal vein, and next into the capillaries of the liver, before it can gain the hepatic veins, and so enter the inferior cava and the right auricle. Hence it has to pass through two capillary networks; that of the intestines, and that of the liver. Thus supposing A (Fig. 118) to be the aorta, the ordinary systemic circulation only goes through the one system of capillaries indicated by *R;* while the portal circulation must pass through the capillary network of the intestines *G*, and of the liver *L*, before it can possibly be transmitted into the inferior vena cava.

682. The chief resistance to the force of pressure exerted by the left ventricle is due to the ramifications of the arteries and to the networks of the capillaries. And hence the doubling of the capillaries which thus occurs in the portal vessels might possibly lead us to think that the ordinary mecha-

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nical forces would be insufficient to maintain the circulation in this segment of the vascular system. But comparative anatomy shows that this is not the case. In the lower vertebrata we find that the blood runs through more than two series of capillaries without the assistance of supplementary hearts.

683. According to Poiseuille, if a limb be so enclosed by a ligature that only one large artery and vein remain pervious, and if a hæmadynamometer be inserted into the latter in the peripheric direction, the mercurial column of the longer leg (*c*, Fig. 8, p. 31) will gradually mount higher than usual, and may finally rise as high as in an artery. Since there is only one path of exit present, viz., that which leads against the hæmadynamometer, this phenomenon may be explained upon hydraulic grounds.

684. Since all the intestinal veins collect themselves into the single vena portæ, it is evident that the blood of the latter must acquire an increased tension. It is possible that this increase of pressure suffices to propel the blood through the second system of capillaries in the liver. Many collateral circumstances will at times help to quicken the normal movement.

685. Just as the intestinal movement impels the chyle in the central direction (§ 556), so something similar to this may be repeated with the venous blood. But if we recollect how long the intestine often remains at rest, we shall not be disposed to assign this phenomenon more than a subordinate import. The respiratory movements may act with more energy. Since the inferior vena cava (*l*, Fig. 119) enters the cavity of the chest close to the liver, and immediately after it has received the hepatic vein, the favourable effect of aspiration will be felt both in it, and in the neighbouring vessels which occupy the liver. While the prejudicial effect of expiration is diminished by the simultaneous contraction of the abdominal muscles, and their pressure upon the viscera of the belly. Hence the blood rather tends to turn aside towards other veins, which, like the jugular, are at the time unburdened by any pressure. But since the valves of this vessel present an obstacle, the influence of expiratory pressure will be transferred to other fluids—for instance, to the arterial blood, which it will propel in the centrifugal or normal direction. So that by means of suitable collateral arrangements, this agent, which might so easily disturb the course of the blood, is made to assist in its circulation.

686. The inferior cava (*o l*, Fig. 119) returns by far the greater part of the blood from the thigh and abdomen into the auricle, while the superior cava (*h*, Fig. 88, p. 174) performs the like office for the arm, the neck, and the head. The right and left azygos veins connect the venous circles which correspond to the two cavæ. For the system of the vena azygos takes chiefly its rise in the lumbar veins. It then receives

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the veins of the intercostal spaces, together with those of the bronchi and the thoracic part of the œsophagus. Its terminal trunk (*q*, Fig. 87, p. 174) opens into the superior vena cava, (*n*, Fig. 87). And thus, if the inferior cava be abnormally occluded, the branches which correspond to it may find a channel of exit leading to the right auricle.

687. In considering the circulation generally, the next question which presents itself is—what is the quantity of fluid continually set in motion by the pump which the heart forms; or how much blood does a man or an animal contain? From the differences in the size of the body, it is evident that absolute weights will teach us very little: and that the estimate must itself form a constant function of some second number.

688. The weight of the entire animal is the most useful basis. But we must not overlook the fact, that even it includes a considerable uncertainty, and this from two causes. It is unquestionable that different tissues contain very different amounts of blood. Thus, for example, the fatty tissue is surrounded by tolerably loose capillaries, while in the muscles these vessels lie close to each other. It is therefore obvious that the total mass of blood will not experience the same increase if the weight of the whole body receives an equal addition from fat in one case, and from muscular substance in another. And in the same manner, the quantities of the non-vascular tissues vary in a remarkable degree. The hair forms a much less considerable fraction of the whole body in man than in the other mammalia. The feathers of birds are in yet larger proportion. In short, the plan of organization possessed by one class of animals may presuppose more blood than that of another.

The repletion of the alimentary canal has an equally important influence. We have already seen (§ 357) what large quantities of the food and its residuum are met with in the digestive organs of herbivora. For example, if a rabbit which during life weighs 16216 grains, contains 3753 grains, or nearly 1-4th of its weight, of food, it is obvious that every estimate of the blood reduced to the weight of the body must vary greatly according to whether we weigh the entire animal, or only its active tissues. The latter would be the only satisfactory experiment.

689. It has frequently been attempted to determine the quantity of the blood by the amount of this fluid which is poured out from an animal bled to death. But such efforts never lead to trustworthy results. The animal perishes from paralysis of the brain as soon as a fraction of the total quantity of blood—a variable one for each individual—has been suddenly removed. And it is easy for any one to convince himself with the naked eye that a considerable amount of blood afterwards remains in the vessels.

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A consideration of the mechanism of the capillaries will better explain what has just been said. The channel of the blood certainly undergoes a great increase in size towards the periphery of the arteries and veins (§§ 648 and 664). But a single glance at the capillaries of an intestinal villus (as exhibited in Fig. 111, p. 199) suffices to show that their total capacity is much greater than that of the corresponding arteries and veins. This disproportion must be still more considerable in those organs in which their intervals form still smaller meshes (Fig. 113, p. 200). If any one would take the trouble to determine, by means of the micrometer, the capacity of the entire capillaries of a series of villi, and then calculate the number of these in the small intestine, and multiply the two numbers together, he would get a quantity of blood which would at first sight seem incredible. And since capillaries containing blood-corpuscles are met with in almost every part of an animal which has been bled to death, it is evident that such a method of inquiry can lead to nothing but error.

690. Hering [21]) attempted, not only to collect all the blood evacuated, but also to separate the residue from the several organs, by mechanical means similar to those adopted by butchers. In this way horses furnished a quantity which was about 1-10th to 1-15th of the whole body: consequently, apart from the fæces contained in their intestines, something more. But this toilsome experiment is invalidated by three considerations. We shall hereafter see that the loss of much blood very soon renders that which remains more watery: the diminished distention of the vessels probably causing a considerable quantity of watery solutions to be taken up from the nutritional fluid. And no mechanical treatment can possibly empty the vessels: hence considerable quantities of blood thus escape calculation. Beside this, it is evident that any compression of the organs would at the same time express their nutritional fluid.

691. Many observers, such as Weber, have filled the vessels with proper quantities of an injection, and have calculated the quantity of blood from the absolute and specific gravity of the fluid used. But this attempt is open to the objection that not all of the capillaries—indeed not even the greater part of them — can be thus filled. And those penetrated by the fluid are generally more violently distended than they are in the living subject. These investigations gave 11·03 to 15·4 lbs. for the human body. But it has sometimes occurred that a woman has lost more than this from uterine hæmorrhage, and still survived.

692. It has been proposed to incinerate, first the solid residuum of a small quantity of the blood, and then the entire animal, so as to deduce the total mass of blood from the relative quantity of iron which the two ashes contain. But to this it may be objected that iron occurs in many other tissues beside the blood; being present in the hair, and in other

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horny tissues which are not penetrated by vessels. The attempt which has been made to solve this problem by means of the circumstances connected with the velocity of the blood's course will hereafter occupy our attention.

693. Suppose we take a solution, the absolute quantity of which is unknown, but which contains a definite percentage of salts. It is evident that we may calculate its quantity by adding a given weight of water, and finding out the new proportion of saline contents. This fact may be used to determine the total quantity of blood.

For instance, we first estimate the solid residuum of a small quantity of blood obtained by venesection. And shortly after injecting a definite quantity of water into a vein, we withdraw a second portion of blood, and again determine its solid constituents. The close resemblance of this operation to the previous example of a saline solution will explain how it enables us to determine the total quantity of blood [22]).

694. Experiments instituted by me upon dogs, cats, rabbits, and a sheep, led to the result that the blood has to the weight of the body a proportion of from 1 to 4·08 to 1 to 6·32. Herbivorous animals had, on an average, less blood than carnivorous. If we take 1-5th as the mean value, a man of 30 to 40 years, whose average weight amounts to 140 lbs., would have 28 lbs. of blood. Wrisberg collected 26 lbs. 7½ ounces from a beheaded woman, and saw 28 lbs. 11 ounces lost by uterine hæmorrhage.

695. It has been objected that the water added does not mix uniformly with the blood. But any one may easily convince himself that two portions of blood — one of which has been taken from the external jugular vein, and the other from the femoral vessels a few minutes after the injection— exhibit but very slight differences in their solid constituents. And since the first venesection only withdraws a very small quantity, there will be scarcely any interference from the absorption of water by the blood. While if the second venesection be not too long deferred, the pulmonary and cutaneous evaporation are not much affected. But if too long a time elapse, and if in the meantime the animal falls into a sweat, the contrary will be the case. Thus an experiment made by me upon a horse, in which this misfortune happened, led to useless results, since the blood had in the meantime lost too much water in other ways. Indeed the exsudation of considerable quantities of water will always cause the observation to miscarry.

One source of error has hitherto not been obviated. We shall hereafter find that the blood is capable of unloading its superfluous water by the kidneys in a very short space of time. And hence, although only a few minutes may elapse between the first and second venæsection, it is still probable that a certain indefinite quantity of water has passed off by the kidneys. The fluid of the second bleeding will

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therefore give too much solid constituents, and the calculated quantity of blood will thus be rendered too large. If we could inject a solution of some substance, which was not contained in healthy blood, which did not pass off by the kidneys, and which allowed of an accurate quantitative determination, the value of this experiment would be greatly increased.

696. The manner in which the total quantity of blood is subdivided amongst the different organs is at present quite unknown. The method of calculation already pointed out (§ 689), might perhaps be applied to some textures,—such as the mucous membrane of the intestine, the whole alimentary canal, the urinary bladder, and many other parts.

697. The frequency of the heart's pulsations varies with the age of the subject. From the tables given by Quetelet, Rameaux and Serrus sought to deduce, that the average frequency of the pulse varied inversely as the square root of the height of the body. But since the fifth power of the weight of the body increases almost uniformly with the squares of its height, it follows, that the squares of the weights vary inversely as the tenth power of the pulse's frequency.

698. At present we have no series of experiments in which all of these constituents—the number of pulsations, the height, and the weight—have been determined simultaneously. Hence we can only transfer the statistical averages of height and weight to the individuals whose pulse has been examined. In adults, the average frequency of the pulse varies so little, and is so greatly raised or lowered by collateral causes, that it is difficult, if not impossible, to determine it. The younger period of life, in which the number of pulsations sinks rapidly with increasing years, is therefore better adapted to this purpose. But if we compare the numbers obtained by Quetelet with those of Guy[33]), we shall see that they differ from each other even more than from the calculated estimates.

AVERAGE FREQUENCY OF THE PULSE PER MINUTE.

Age in Years.	Determined by experiment.		Calculated after Rameaux and Serrus.	
	Quetelet.	Guy.	From the average Height.	From the average Weight.
New born	136	..	129·8 to 129·5	127·3 to 126·1
5	88	93	92·0 „ 91·3	92·5 „ 91·6
10 to 15	78	88	80·4 „ 73·1	83·0 „ 75·5
15 „ 20	69·5	77	73·1 „ 70·2	75·5 „ 70·8
20 „ 25	69·7	78	..	70·8 „ 70 2
25 „ 30	71	74	72·3 „ 71·0	70·2 „ 70·0
30 „ 50	71	75 to 71	73·3 „ 70·0	70·2 „ 69·8

699. Assuming 70 to be the ordinary pulse of an adult man, each beat of the heart lasts ·86, or nearly 17-20ths, or 4-5ths of a second. If we further suppose that, under normal circumstances, the systole and

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diastole of the ventricles last about equally long, each of these acts would demand 2-5ths of a second. The pendulum tests instituted by Volkmann and myself frequently came near to this calculated value. My average amounted to ·425, or very nearly 2-5ths of a second: but the total series of researches only furnishes approximative estimates. In some persons the ventricular systole is distinctly longer than the diastole.

700. The umbilical cord of the new-born infant beats about 140 to 144 times in the minute, or twice as frequently as the heart of the adult. It has been often believed, that in old age the average is remarkably diminished. But statistical observations in almshouses show that, as a rule, this is not the case. We frequently get 72 to 83 as the average frequency of the pulse between 70 and 90 years. So that if this phenomenon be not based upon any morbid circumstances, it would seem that, during the last years of life, the pulsations are even increased in number.

701. All febrile excitements increase the number of beats. From this cause the pulse of the adult may equal, or even exceed the frequency seen in the new-born infant. On the other hand, many persons exhibit an unusually slow pulse. Guy mentions a healthy man with only 38 beats in the minute, and Fordyce one with only 20.

702. The heart of the female beats on an average more quickly than that of the male. This law appears to hold good for all periods of life. The pulse is proportionally slowest in the recumbent posture; it is quicker in the sitting, and quicker still in the standing, attitude. Since violent muscular exertion usually accelerates the pulsation of the heart, this difference might have been attributed to the muscular activity connected with the different postures. But Guy remarked it in men who were firmly tied to a board. How far it is influenced by the attention remains at present undecided.

The frequency of the pulse is diminished during sleep. It is increased by the use of stimulating food, and especially of spirituous drinks, by mental excitement, by muscular effort, by great heat, and, according to some, by a diminution of atmospheric pressure.

703. We may assume that, as a rule, there are from 3 to 4 beats of the heart for every respiration. The average for both child and adult is from 3· to 3·8. Quetelet estimated it as 4·4 from the age of 25 to 30: and Guy as 4·2 to 4·3 for that of 75 to 85.

704. The respiration and the movement of the heart have an intimate mutual action on each other. The heart of a newly killed animal, which has ceased to beat, may often be aroused to contract by blowing in air through the bronchi, and sucking it out again. And by such an artificial respiration the existing pulsations of a dead animal may also be sustained longer than they would have continued without its assist-

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ance. And *vice versâ*, since the chief object of respiration is the alteration of the blood which flows through the lungs, it is evidently dependent upon the activity of the heart.

705. This intimate connection of the two phenomena does not, however, necessarily imply their rise and fall in the same proportion. Guy found that on an average there were 3·6 pulsations of the heart for one respiration in the morning, and only 3·4 in the evening. The recumbent posture gave 5; and the attitudes of sitting and standing 3·4 and 3· respectively. The age of from 50 to 60 gave 3·7 for the male, and 3·6 for the female: that from 80 to 90, 3·, and 3·5 to 3·2.

706. We have already seen (§ 580) that the capacity of the cardiac cavities cannot be safely determined from their condition in the dead subject. From many measurements which have been undertaken with this view it would follow—with, at most, only a certain degree of probability — that the ventricular systole of a strong adult man generally impels from 3·5 to 5·3 oz. of blood into the pulmonary, and about as much into the systemic, circulation.

707. At present we have no other experimental means of giving a trustworthy answer to this question. But many facts appear to indicate that the estimates just mentioned are not very far from the truth.

By means of ligatures, Abegg [24]) closed the outlets of the beating heart in eight rabbits; and found that the weight of the blood which was contained in the cardiac cavities came tolerably near to that of the heart itself. The smallest weight of this organ amounted to 31·66 grs., while its contents were 29·65 grs. of blood. Their maximal quantities were 73·67 and 56·53 respectively. Taking the mean of all eight observations, he obtained 47·88 for the heart, and 40·15 for the free blood which it enclosed. And recollecting that, in addition to this, there is a certain quantity of blood retained in the coronary vessels of the heart, and the capillaries connected with them, we shall not err much in assuming the blood to be about 9-10ths of the weight of the heart.

The ordinary weight of the human heart ranges between 6·7 and 13·4 oz. And hence assuming the proportions mentioned above for the heart of the rabbit, it would contain from 6 to 12 oz. of blood.

That short interval which sometimes, but not always, separates the end of the ventricular systole from the beginning of the subsequent auricular contraction may be disregarded. Supposing this to be the case, the auricles only fill during the systole of the ventricles; while the ventricles are only distended during the contraction of the auricles. Hence it will probably be most correct to regard the total quantity of blood cut off in the heart as distending to their uttermost both ventricles or both auricles. Abegg certainly states that his ligatures were applied to the arteries first, while the veins remained open. But recollecting that the exposed heart of the rabbit beats more rapidly than

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the human organ, and that the only ligature present could not act sufficiently until it was tightened, we shall find the above interpretation of the facts a not improbable one. Thus, supposing the right and left ventricles of the living human heart to possess the same capacity, each of them will expel from 3 to 6 oz. of blood, or on an average about 4½ oz. While the numbers deduced from the dead subject amounted to from 3·5 to 5·3, or to about 4·4 (§ 706).

708. We have seen (§ 37) that the mean specific gravity of the blood amounts to 1·06, so that 4·4 oz. would give 7·2 cubic inches. Hence the quantity which is expelled at every ventricular contraction will dislodge the blood of a considerable part of the commencement of the arterial system. Wishing to get a more accurate idea of this fact I selected a preparation in which the abdominal aorta of an adult man had been completely filled by injecting it backwards or towards the heart. The mass of wax ended at the semilunar pouches, which were fully and normally distended. The mass of this substance which filled the ascending aorta, (*e*, Fig. 87, p. 174), its arch (*f*), and the descending aorta (*g*), as far as to a level with the inferior border of the semilunar valves, together with the first inch of the innominate, left carotid, and left subclavian trunks, and the first quarter of an inch of the coronary artery, amounted altogether to 7·3 cubic inches. Hence each stroke of the heart impels about this quantity of blood. But since the resistances of the several vessels are unequal, it is obvious that the blood is not necessarily driven into exactly those segments of the vessels just mentioned.

When I cut off the mass of injection close above the upper margin of the shut semilunar valves of the aorta, I found that two of these contained rather more, and the remaining one rather less, than 1-6th of a cubic inch. Supposing all three to contain about ·55, it will follow that about 1-13th to 1-14th of the quantity impelled at each systole of the ventricle recedes during its diastole. But all the remainder is given up to the normal and centrifugal propulsion.

709. From calculations the basis of which is as yet unknown, Guettet supposes that the mean velocity of the arterial blood between systole and diastole amounts to 19·7 inches. Volkmann and Huettenhein[25]) endeavoured to form a direct estimate of the speed with which the blood runs in a given artery of any particular mammal. They replaced a certain extent of the vessel with a brass tube, having a diameter of 1-9th of an inch, and to which was adjusted an arched glass tube opening by both ends into its sides. Two stop-cocks, which were applied to this hæmadromometer, allowed the blood to flow, either straight through the brass tube, or by the roundabout path through the glass one, which was filled with water, or a solution of carbonate of soda or common salt. And as this latter could be observed by the eye, the velocity of its contents

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was capable of being directly determined by the aid of the second-hand of a watch.

An experiment made upon the carotid of a dog gave a velocity of $10\frac{3}{4}$ inches in each second. Three observations on the horse gave 21·5 to 24·8 inches. All these numbers were found with an arrangement which turned each of the cocks singly: and hence there was some risk that their apertures were not thrown open simultaneously. But by using an apparatus in which both were turned at once, the carotid of a goat gave 12·5, and the artery of a horse's foot 2·2 inches.

Still, neither the metallic tube nor the glass one which directly furnishes the observation, possess the same calibre as the excised piece of artery. And they are also devoid of its elasticity, as well as of the smoothness of its inner surface. In addition to this, they compel the blood to deviations which imply a certain amount of resistance. While the water and the solution of soda or salt form a foreign fluid, which is partly mixed with the blood, partly penetrated by it, and which has not the same temperature. Some of these collateral circumstances will diminish the velocity: while the mixture of the blood—which is only recognizable by its colour—with the colourless fluid of the glass tube, and the want of elasticity, would have the reverse effect. It is therefore very questionable whether a correct estimate of the velocity can ever be attained by this method.

A closer examination of the estimates obtained will but support this conjecture. The blood is represented as flowing twice as fast in the carotid of the horse as in that of the dog; and the number found in the goat only amounts to half the maximum of the horse. But the current forces are tolerably equal in all three: and the proportional capacities present no very considerable difference. A greater velocity of the circulation might be produced by an increased number of beats of the heart. But the horse exhibits only 40 to 50 in the minute, while the goat generally offers 80 to 85, and the dog 90.

710. It might, *à priori*, be expected, that the velocity of the contents of the larger arteries would vary considerably in short spaces of time. For the channel remains tolerably constant; while the strength and velocity of the heart's stroke, and the positive or negative amount of respiratory influence, are all liable to variation. Hence any determination of the mean velocity must be deduced from large series of observations, repeated upon the same vessel, under every possible variation of the normal circumstances.

711. We have already seen (§ 645, *et seq.*) that the velocity of the circulation is continually diminished in the course of the arterial ramifications, by the dilatation of the channel, by the enlargement of the surfaces of friction and adhesion, and by the gradual levelling of the expiratory waves. Hence the fluid arrives at the capillaries with a

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very moderate velocity, and proceeds in these even more slowly. But since all these elements vary for different parts, it is evident that the rate of velocity will also be unequal in different places.

712. Hales ascribed a velocity of $\frac{1}{85}$th of an inch per second to the blood in the capillaries of the abdominal muscles of the frog, and a speed 45 times as great to that contained in those of the lungs. In experiments upon the larva of the frog, E. H. and Edward Weber saw the blood-corpuscles moving with a velocity of $\frac{1}{6}$th to $\frac{1}{4}$th of an inch; while the lymph-corpuscles rolled onward with a speed of $\frac{1}{77}$th to $\frac{1}{52}$d. The capillaries of the frog's web yielded me an average velocity of $\frac{1}{50}$th of an inch; which, however, sometimes sank to $\frac{1}{125}$th. Those of the larva of the frog showed an ordinary speed of $\frac{1}{75}$th to $\frac{1}{100}$th: and the embryo of the pike and perch afforded similar results. So that taking $\frac{1}{125}$ to $\frac{1}{62}$d as the basis, a distance of one yard in length would require from 38·4 to 76·9 minutes.

713. We shall soon find that it is probable the whole blood can pass once through the blood-vessels of the lungs and body in less than two minutes. Hence the slowness of the capillary circulation just mentioned might, at first sight, seem somewhat strange. But we have only to consider that the blood-corpuscle, when not disturbed in its movements, has but to pass through a very short extent of the capillaries, and is soon transferred to a venous trunk. It will therefore follow that this slow progress in the finer vessels is outweighed by a greater speed in the larger ones. So that the average velocity of the entire movement may be considerable. And a glance at the circulation in the capillaries often suffices to show how much greater is the velocity of the corpuscles when they occupy one of the smallest arteries, or enter the rootlet of a vein.

714. Hering was the first who attempted to determine by experiment the mean time of the circulation. He injected a solution of ferrocyanide of potassium into the jugular vein of the horse in the central direction, and at the same time allowed the blood to flow out of a second vein—such as the femoral vein—into vessels which were changed every five seconds. After the separation of the serum, he tested it with chloride of iron. The portion in which the first precipitate of Prussian blue appeared afforded the desired estimate of time. For, supposing that the prussiate of potash can only proceed mechanically by means of the circulation, it must pass through the termination of the jugular vein, the superior cava, the right heart, the entire pulmonary circulation, the left heart, and the arterial system, to the capillaries of the foot; and through these and the corresponding veins to the cutaneous vein of the thigh—*i.e.*, it has to go through the whole of the pulmonic, and the greater part of the systemic circulation.

715. Hering found that, on taking the blood from the other jugular or great cutaneous femoral vein, or from the external maxillary or middle

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plantar artery, the times varied from 10 to more than 40 seconds. Poiseuille found 25 to 35 for the other jugular vein. The latter observer thinks a similar experiment proves that certain applications are capable of altering the velocity from merely physical causes. A solution of acetate of ammonia streams through small glass tubes more rapidly than pure water: while alcohol runs more slowly than the latter. And the same horse which gave 25 to 30 seconds with the simple solution of the ferrocyanide of potassium gave 18 to 24 with a second one containing acetate of ammonia, and 40 to 45 with a third containing alcohol.

716. The frequency of the horse's pulse does not necessarily rise in consequence of the injection of ferrocyanide of potassium. Besides this, Hering obtained pretty nearly the same result, whether the pulse was quicker or slower. This fact need not surprise us. For the experiment only furnishes us with the times in which the first portions of the ferrocyanide of potassium chance to gain the blood of the vein. And hence the greater frequency of the heart's beat may be compensated by the expulsion of a smaller amount of blood with each ventricular systole.

Two circumstances may possibly have made the times found in these experiments too short. The solution of the salt is not propelled in a simple mechanical way, like the mass of the blood-corpuscles, but mixes with the moving liquid. Besides this, it is capable of a further diffusion in the nutritional fluid. It is possible that certain quantities of the salt are thus transferred from the right to the left ventricle, without going through the pulmonary circulation. Future experiments must decide the accuracy of these suggestions.

717. If we suppose that each of the 70 beats generally given in a minute by the adult heart, impels 4·4 ounces of blood into the systemic, and the same quantity into the pulmonic, circulation, the total quantity for that unit of time will be 308 ounces. But since this is more than half of the whole mass of blood, the duration of the circulation must, upon this supposition, be less than two minutes.

718. In treating of nutrition, we shall find that many substances may, without injury, be injected into the veins: while others are hurtful by their powerful chemical properties, or fatal by the nervous paralysis which they induce. The atmospheric air, upon which the renovation of the darkened blood depends, and which is able to revive the heart of a newly killed animal after it has come to a stand-still, is yet on account of its mechanical properties, capable of acting like the deadliest poison.

719. It has occasionally happened that men undergoing operations in the lower part of the neck have died under the hands of the surgeon without any loss of blood, or division of a nerve which might explain this

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unfortunate result. During the aspiration of breathing, (§ 739) air has been heard rushing into the wounded jugular vein. If small quantities of air be injected in the central direction into the cervical vein of a living horse, the animal may still continue to live. But if the quantity be more considerable—some hundreds of cubic inches,—death usually follows in a few minutes.

720. This injurious effect probably depends upon the fact, that the particles of air, which are contained in the glutinous blood as in an emulsion (§ 493), block up a large part of the capillaries of the lungs, so as greatly to check the circulation, and thus produce suffocation. Since the transverse section of the finest capillaries of the human lung is as little as 1-200,000,000th of a square inch, a few hundred cubic inches of very finely divided air would suffice to block up the greater part of these delicate vessels. But at present we are altogether devoid of such accurate quantitative estimates as would verify this explanation.

721. In beheaded men and mammalia it may be remarked, that the left ventricle ceases to contract before the right one. And since the arteries undergo their utmost possible narrowing shortly after death (§ 637), the greater part of their blood is driven on into the capillaries and veins. And should the blood coagulate before the elastic walls (§ 637) of the arteries recover their capacity, their cavities can afterwards only be distended by the gases they absorb. This explains why most of the systemic arteries are found — as we generally express it — *empty* after death. It is also obvious that the phenomena will be altered by any want of coagulability: many arteries are in fact found to contain fluid blood.

722. Since the mere repletion of the vessels considerably stretches their coats, the movement of the blood does not cease at the instant of removing the heart. If coagulation offers no additional obstacle, blood flows out of the cut extremities of the vessels until the quantity of their contents forms a counterpoise to the condition of their coats, and the external pressure. Hence long after the excision of the heart an uniform movement of the blood may be seen in the capillaries of transparent parts. The opinion of earlier observers — that this phenomenon proves the independent agency of the capillaries in the circulation — evidently rests upon an incorrect interpretation of this fact. And the stream thus remarked in the capillaries differs essentially from that observed during life.

723. In the dead subject, the blood frequently gravitates towards the lowest parts. In this way are produced the reddish-blue or violet discolorations seen in corpses. Since coagulation consists in the separation of the fibrin, the serum must necessarily be more watery than the living liquor sanguinis. But every watery solution alters the blood-corpuscles. They swell and lose their flattened form; taking up water and solid

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constituents, and giving off the red colouring matter of the blood. A more or less red fluid is thus produced, which extends itself by diffusion. Hence many parts of the corpse — as for instance the arterial coats — are frequently coloured red; just as the neighbourhood of the gall bladder is rendered yellow. But the green or yellowish green streaks which appear in the progress of decomposition exclusively depend upon new combinations, which have been produced by a more advanced stage of putrefaction.

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CHAPTER IX.

RESPIRATION.

724. Since the external surface of the animal body is either surrounded by the atmosphere, or by water impregnated with air, the blood which circulates in the skin will unload itself of a certain quantity of carbonic acid, and will take up a certain quantity of oxygen (§ 154). It is thus, in one word, renovated. But as the quantity of blood thus metamorphosed is much less than that which is simultaneously wasted in the other parts of the body, there arises a necessity for special organs of respiration, in which larger quantities of blood may be reddened anew. Hence animals living in the air have lungs, and aquatic creatures, gills.

725. The chief requisite consists in the action of the largest possible surface of air on a similarly extensive surface of blood. In treating of secretion we shall hereafter see that this problem is completely solved by arborescent ramifications. In this way many varieties of gills form dense branches, which are penetrated internally by a network of blood-vessels, and externally, are bathed in water. In the highly developed lungs of man and the mammalia, the bronchi or first bifurcations of the ramified air-tube constantly divide into trunks, which gradually diminish in size, and finally end in blind extremities at the pulmonary vesicles. And even the latter structures contain folds, which further increase their surface. The lower air-breathing animals have a simpler development of the lungs. They form a cavity, from which sometimes proceed a number of secondary cavities, separated by reticular partitions. Such a condition may be seen in the reptilian lung-sac, the breathing activity of which increases with the number of partitions it contains. And finally we arrive at the still more simple air-sac met with in many of the pulmonate snails.

726. Respiration is intended to make the dark-red blood scarlet. While nutrition, which is chiefly carried on by the capillaries, leads to the converse change of colour. But the organs of respiration, like other parts, require renovated blood for their own maintenance. And there are two ways in which this could be furnished. The veins returning in the interior of these organs might give off branches continuous with the nutritive capillaries. Or the aorta and its subdivisions might furnish branches, to be distributed in the lungs as in other tissues. Nature has preferred this second method, both in the lungs and gills.

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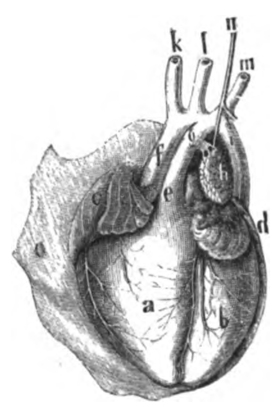
727. In the air-breathing animals, the nutrient capillaries of the lungs proceed from bronchial arteries, which are given off by branches of the systemic aorta, while the respiratory capillaries come from the pulmonary artery. The bright-red blood impelled into the former becomes dark; while dark venous blood is received by the latter, to be discharged, when renovated, into the pulmonary veins.

728. When distended with air, the lungs of an adult man weigh about 18 to 53 oz. Hence, taking the average weight of the body in both sexes as being, in round numbers, 132 lbs., the lungs form about 1-120th to 1-40th. And even supposing the lung to require a comparatively large amount of nutrient blood, still its quantity must be but a fraction of the respiratory blood, since this renovates all the fluid which has become dark-red in the other parts of the body. In fact, we have already estimated (§ 717) that about 308 oz. of blood would pass through the lungs of a strong man in every minute.

729. The veins of the skin convey a dark-red blood. Hence, it follows that that mutual action which may obtain at the outer surface of the body is incapable of overcoming the counter-influence exercised by the nutrition of the skin. In accordance with this fact we shall find that the changes produced in the air by the lungs are much greater than those effected by the skin.

730. So far as we know, the bronchial vessels of the adult are nowhere in direct communication with the vessels of respiration. The right and left heart, and the larger trunks of the pulmonic and systemic circulation, are here completely separated. Hence the systemic arteries and pulmonic veins only convey bright-red blood; while the systemic veins and pulmonic arteries contain none but the dark-red fluid.

Fig. 120.



731. But the case is very different in the new-born infant, in the lower air-breathing vertebrata, and in the different divisions of reptiles. Fig. 120 represents the heart of an eight months' child, which had lived two days after birth. It is drawn half the natural size. Here we see a canal—the ductus arteriosus, *g*, which passes from the pulmonary artery, *e*, to the aorta, *f*. And since it conveys venous blood, part of this fluid will immediately enter the aorta, and will mix itself with the bright-red blood which comes from the left ventricle, *b*, so as to communicate a darker shade of colour to the blood flowing into the other systemic arteries, *f k l m*.

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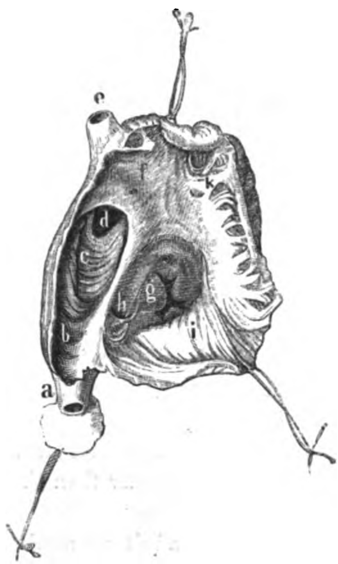
If we look at the excised auricle of the same heart, as it is represented of the natural size in Fig. 121, we find a second arrangement, which conduces to the same purpose. We remark that the valve, *c*, of the foramen ovale, *d*, does not shut perfectly. Hence the auricular partition leaves a wide aperture, *d*, which unites the cavities of the two auricles. A part of the dark-red blood of the right auricle will, therefore, flow directly into the left one. The current of the vena cava superior, *e*, meets with a furrow, *f*, which conducts it towards the right auriculo-ventricular aperture *g*, and thence towards the right ventricle; while that of the inferior cava, *a*, glides easily along its conducting groove, *b*, to the aperture of the foramen ovale. In treating of development we shall find, that in the fœtus these various paths have definite objects. But in the newly born infant such secondary purposes are no longer present. So that if a certain quantity of the blood ascending in the inferior cava sometimes escapes transit through the lungs, and mixes immediately with the renovated blood, it constitutes a fault, although an unimportant one.

FIG. 121.



732. In the infant the ductus arteriosus (Fig. 120, *g*), and the foramen ovale (Fig. 121, *d*) are generally shut. But it sometimes happens that this aperture in the auricular partition is abnormally retained. This is not unfrequently the case in humpbacked persons, in whom the crookedness of the chest prevents the necessary extension of the lungs. And other degenerations of the organs of respiration may lead to the like results. Finally, congenital malformations of the heart and large vessels sometimes cause large quantities of dark-red blood to be mixed with the brighter fluid.

733. If the systemic arteries contain but small quantities of non-renovated blood, this will not much affect the colouring of the whole. But if larger quantities are admixed, the nutrient capillaries of the body receive an extremely dark blood. This glimmers through the semi-transparent structures, such as the conjunctiva of the eye, the lips, the external circumference of the nostrils, the outer ear, the labia pudendi, and the surface of the nails. And since all these parts are thus coloured blue, the abnormal condition has been named *cyanosis*. Persons

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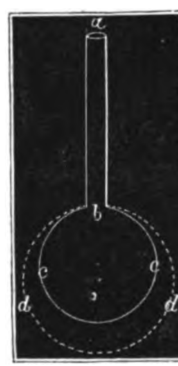
suffering from this disorder never live to be old: they are weakly, and often suffer from dyspnœa. And an apparently unimportant pulmonic disease may carry off a humpbacked person, whether the foramen ovale be open or not.*

734. Since the gills protrude free, the blood flowing within them constantly comes into contact with fresh portions of the surrounding water, if this is moved by any secondary cause. Still nature almost always provides a special mechanism, by means of which the fluid once used is removed, and new portions brought forward. But in the case of the lungs, the respirable air has to act within the cavities of the ramified air-tube. Hence a pump-work is here indispensable to the exchange of the air. The change of bulk due to the air being warmed, or charged with watery vapour, would not effect the gaseous exchange with that velocity which collateral circumstances require.

735. When the tube *a b*, Fig. 122, remains open at *a*, the air contained in the cavity *a b c c* has the same tension as that ordinarily possessed by the surrounding atmosphere. But if we suppose *c c* to be suddenly dilated to *d d*, the space *a b c c* will be suddenly enlarged to *c d d c*. The gas included in *a b c c* must be rarefied in proportion to the increase of space, and its tension must be correspondingly diminished. Hence the increase of bulk leads to a certain negative pressure, the amount of which equals that of the reduction in the previous atmospheric tension. But since that of the surrounding air remains the same, new air will rush in from *a*, until the pressure in both places has become equal. If, after this has happened, *d d* returns to its previous bulk *c c*, the diminution of space will tend to condense the air contained in *a b d d*, and will raise its tension. Hence we get a corresponding surplus of tension, or a positive pressure, which expels a certain quantity of air from *a*.

FIG. 122.



736. For example, supposing *a b c c* amounts to 100 cubic inches, and *c d d c* to 10 cubic inches, the space will be increased one-tenth by the conversion of *a b c c* into *a b d d*. The tension is therefore diminished by one-tenth. Hence, with the outer air at 29·9 inches of barometric pressure, it would sink to 29·9—2·99 = 26·91, and would only recover the tension of 29·9, when 10 cubic inches had entered. But if *a b d d* subsequently returns to *a b c c*, the bulk is diminished by 1-11 of the present contents of 110 cubic inches; and 1-11th of the now disproportionate

* It is, however, important to observe, that this imperfect aëration of the blood, whether due to a cardiac or thoracic imperfection, appears equally to exempt the sufferer from that tubercular disease which, under the name of consumption, forms so large a percentage of fatal pulmonary disorders.—EDITOR.

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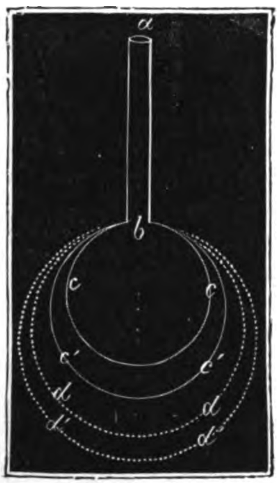
pressure will—if no other obstacles intervene—be able to remove 10 cubic inches.

737. If we now suppose that *c c*, Fig. 123, is surrounded by a second bladder *c′ c′*, and the space *c c′ c′ c* is shut air-tight, and filled with a liquid —if *c′ c′* becomes *d′ d′*, and the walls are sufficiently yielding, the same process will be repeated. The zone *c c′ c′ c* is then converted into *d d′ d′ d*, which has the same capacity. But *c c* is dilated to *d d*, and takes in a corresponding quantity of air. If *d d′ d′ d* be subsequently reconverted into *c c′ c′ c*, *d d* also returns to *c c*.

FIG. 123.



738. If we imagine *c′ c′* to be the wall of the chest, which is covered by the costal pleura; *c c*, the lungs clothed with their pleura; the fluid between *c c* and *c′ c′*, the serous secretion of the pleura; *ba*, the trachea; and *a* the glottis; we shall have a diagram of the mechanism of human respiration. If the capacity of the thoracic cavity be enlarged from *c c* to *d d*, the serum contained in *c c′ c′ c*, adapts itself to its new position in *d d′ d′ d*. A quantity of air corresponding to the enlargement of capacity, *c d d c*, will therefore be drawn in from the glottis. Upon this process the act of inspiration depends. While that of expiration consists in the return of the thoracic walls from *d′ d′* to *c′ c′*, and the expulsion of air at *a*.

739. This alternate play of force may be better illustrated by Fig. 124. When the diaphragm, *m n o*, is in a state of rest, it forms an arch with its convexity directed towards the thorax. During inspiration it contracts, and becomes flat. Hence a great part of the space, *m n o*, is gained by the thorax. The transverse diameter of the chest is also enlarged, by means of muscular contractions which will shortly be mentioned. We thus get another increase of size. The negative pressure so produced sucks in fluids wherever it can, in order to restore its equipoise with the tension of the outer atmosphere. In this way chyle, lymph (§ 559), and venous blood (§ 674), are impelled towards the thorax; and the peripheric course of the arterial blood is somewhat interfered with (§ 625). But since the external air can enter freely through the glottis, it is the main agent in overcoming this disproportion. A certain quantity of air therefore flows in during inspiration.

740. The act of expiration is effected by the mere elasticity of the tissues displaced in the instant immediately preceding. The relaxed

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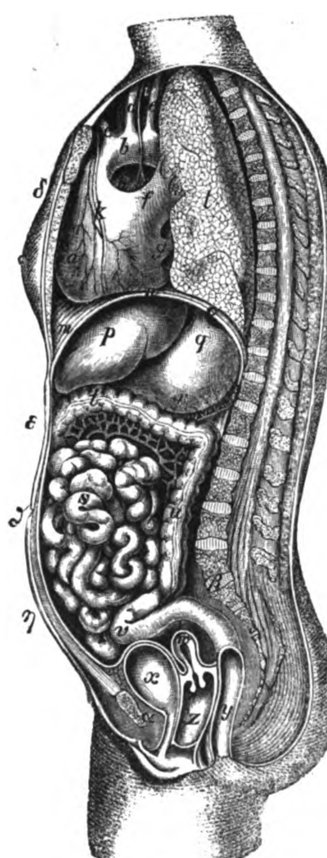
diaphragm, which is antagonized by the pressure of the abdominal viscera, returns, of its own accord, to its previous situation (*m n o*, Fig. 124). The remainder of the thoracic dilatation was chiefly accomplished by a bending of the costal cartilages; the elasticity of which causes them to spring back again on its cessation. Hence the transverse diameter, (γ δ), and the height, of the thoracic cavity are at once diminished. And thus, while inspiration can only result from the action of muscles, the simplest act of expiration is due to a physical reaction which immediately follows the relaxation of these contractile textures.

741. If larger quantities of air are to be expelled through the glottis (*i*, Fig. 128, p. 232), the abdominal muscles may assist. The diaphragm, *m n o*, Fig. 124, which is flattened during inspiration, carries the intestines before it, and tends to arch the abdominal wall, ϵ ϑ η, outwards. But when the muscles of the belly contract vigorously during a powerful expiration, ϵ ϑ η approaches the vertebral column. The abdominal viscera then press the diaphragm, *m n o*, powerfully upwards towards the thorax. The capacity of this cavity is therefore diminished. Still we shall soon find that the abdominal walls may enact other parts during deep respiration. Besides this the thorax may be drawn downwards, so as to give additional force to the act of expiration.

Fig. 124.



742. The ordinary tranquil inspiration of man only requires the contraction of the diaphragm, and a slight enlargement of the thorax in its transverse diameter. But deeper or more violent respiration demands the assistance of additional muscles. When respiration is in danger, this group is capable of being greatly increased.

If we examine into these circumstances in the different ages of man, or in the several mammalia, we shall find that many regions of the thorax take a special share in this alteration of capacity. If the play of the abdominal muscles predominates, we

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speak of *abdominal* respiration. In some cases the inferior, and in others the superior, half of the chest undergoes the most visible displacement. Hence we get an upper, or a lower, *costal* respiration. The latter chiefly occurs in adult males, the former in females. While, according to Beau and Maissiat, the abdominal respiration prevails in the new-born infant.

743. Some of these relations may be more clearly explained by means of the diagrams supplied by Hutchinson[26]. In Fig. 125, are exhibited

FIG. 125.

FIG. 126.

these changes in an adult man, whose back is fixed: while those of the female are seen in Fig. 126. The free black line exhibits the slight variations which accompany tranquil respiration; its anterior margin limiting the inspiratory, and its posterior the expiratory act. The dotted line represents a deep inspiration, and the anterior margin of the black trunk a deep expiration. We see that, even during tranquil respiration, the lower part of the thorax, and the upper and middle parts of the abdominal walls, present wider intervals in the male than in the female. And deep inspiration leads to yet more remarkable differences in this respect. The upper costal respiration of woman becomes very distinct: while the abdominal walls, instead of being at that time pushed forwards, so as to be convex, seem rather contracted and receding behind the dilated thoracic cavity.

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744. The muscles capable of sharing in the more violent movements of respiration may be divided into three classes. The muscles of inspiration enlarge the capacity of the thorax; while those of expiration diminish it. But since many which are required in powerful inspiration, can only act with full effect when other muscles have fixed the levers from which they arise, we thus obtain a third series of contractile structures, the muscles of fixation, which indirectly assist in respiration.

745. On examining the thorax (*c*) of the adult human skeleton represented by Fig. 127, we see that the ribs are capable of altering the capacity of its cavity in two ways. If they previously run obliquely from above downwards, their being raised to the horizontal situation will carry the sternum forwards, and will thus increase the antero-posterior diameter of the thoracic cavity. If, at the same time, they extend the cartilages of the ribs in the direction from within outwards, and are themselves drawn outwards in like manner, the lateral diameter will also be increased. While this is going on, the contracting diaphragm exerts an influence upon the longitudinal diameter of the thoracic cavity, and tends to compensate the disadvantage in this respect which is produced by the elevation of the ribs. So that the simultaneous play of the diaphragm and of the ribs is capable of elongating all three diameters of the thoracic cavity.

746. Since the ribs and the more yielding costal cartilages, alike experience a general increase in length from above downwards, it follows that the lower half of the chest presents more marked results. The traction exercised in the neighbourhood of the vertebral column (*d*, Fig. 127) will move them through a space which is greater, the longer the arms of the levers they form. So that even supposing the agents of contraction equal, the inferior half of the thorax would have the advantage.

747. The following muscles are capable of sharing in the movements of powerful inspiration: the diaphragm, the intercostals, the infracostals, the long and short levatores costarum, the scaleni, the serratus posticus superior, and the other serrati, the trapezius, the rhomboids, the levator anguli scapulæ, the latissimus, the sterno-mastoid, the cervicalis ascendens, and the subclavius. Deep expiration demands the aid of abdominal muscles: viz., of the obliquus externus and internus, the transversalis, rectus, and pyramidalis. The quadratus lumborum can afford a certain amount of assistance. Many include among the muscles of expiration some fibres of the intercostals. The triangularis sterni also probably belongs to the same class.

748. Since most of the contractile masses just mentioned proceed from the skull *a*, (Fig. 127, p. 230), the vertebral column, *b d*, the scapula, *e*, or the clavicle, *f*, all the muscles which maintain these parts of the skele-

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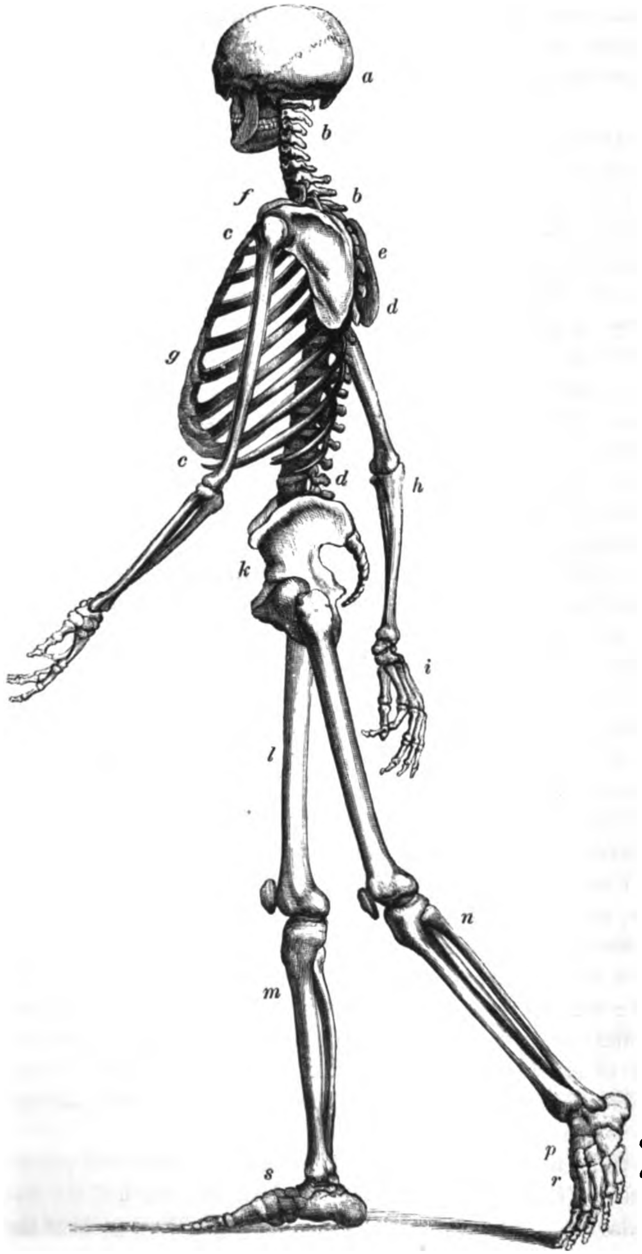
ton in their proper situation will, under suitable circumstances, act as muscles of fixation. The splenius capitis and colli, the biventer cervicis and

Fig. 127.



complexus, the trachelomastoid, the recti and obliqui capitis, the longissimus dorsi and sacrolumbalis, the spinales and semispinales, the multifidus spinæ, the muscles intervening between the smaller processes of the vertebræ (such as the interspinales, intertransversales and rotatores dorsi), and even some of the muscles of the arm — all belong to this group of contractile structures, which occasionally come into use.

749. It is unquestionable that the number of muscles so employed must vary with the mode in which, and the force with which, respiration is accomplished. But it has hitherto been found impossible to analyze some of the elements which unite to form these groups, or to show how the actions of the individual muscles are co-ordinated into a whole. The varying form and mobility of the hard tissues, and probably the nature of the nervous influence by which the movement is excited, exercise a great influence. Hence we ought to be very cautious in applying the results obtained from a tortured living animal to the normal condition of the same creature — much more to that of man. And since the question cannot be solved by an examination of the muscular attachments after death, it will probably be long before our knowledge of the mechanism of respiration is rescued from this vague and unsatisfactory state.

750. It is obvious that, when the lungs are distended, the outer air begins to pour in; and that similarly, at the commencement of expiration, the air in the lungs begins to stream out. But since the channel continually widens as it proceeds towards the pulmonary vesicles, the inspiratory stream must—under the same distribution of pressure (§ 106) —exhibit a decreasing velocity, and the expiratory current an increasing one. While the cartilaginous rings of the air tubes, which are continued into their finer ramifications, prevent that energetic pressure which effects the expulsion of the air from shutting, or even unduly narrowing, the path of its exit.

751. Since the transverse section of the glottis (*i*, Fig. 128) is considerably smaller than that of the trachea, the respired air streams out through a narrowed orifice of exit. And mechanical science teaches, that such an arrangement greatly increases the quantity of gas which is poured out from a bellows, at a given pressure, and in a given space of time. If the glottis of a living mammal be laid bare, it may be seen to dilate visibly during strong inspiration; while conversely, it narrows during powerful expiration. Hence that alternation of phenomena which occurs during life tends to assist the efflux of the respiratory gases.

752. The air which passes the epiglottis (*h*, Fig. 128) may take either of two paths of exit. It may pass from the pharynx, (*g*) between the tongue (*c*) and the palate, (*e d b*) to emerge from the mouth. But it may also enter the nasal fossæ, (*a'*) through the posterior nares, (*f*) and pass out of the nostrils. Hence we are able to inspire and exspire, either through

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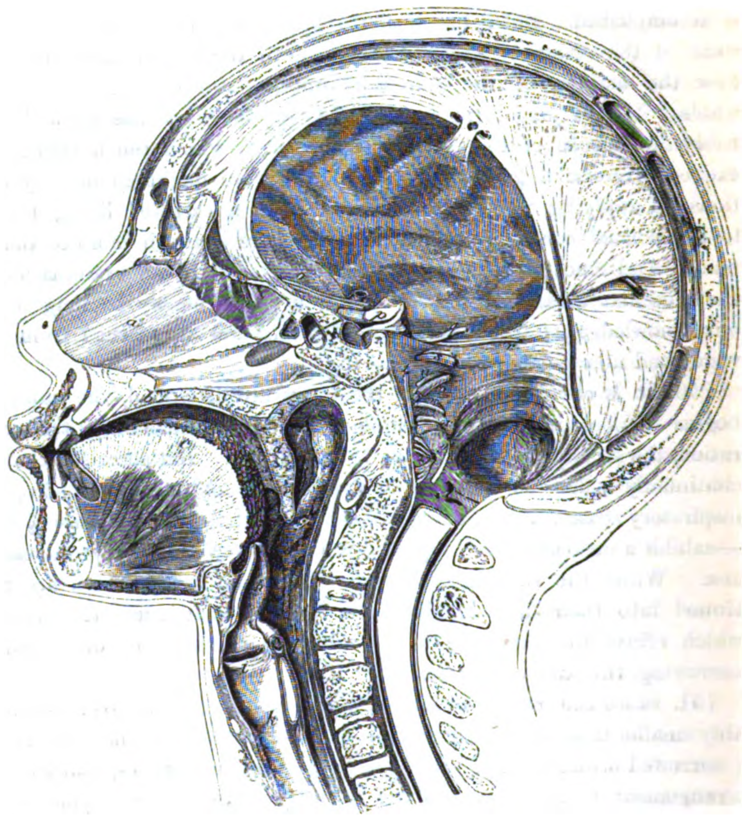
the cavity of the mouth, or the nasal fossæ, or both simultaneously. But although the two canals of outlet appear to be equally open in the dead subject, yet we find that, if both nose and mouth be open, and no volitional influence exerted, the whole stream of air will be expelled from the oral aperture. Still we can produce at will any of the three different forms above mentioned.

FIG. 128.



753. The thyroid cartilage descends in deep inspiration, and ascends in forcible expiration. Differences of this kind may be produced by mere mechanical traction. The alæ of the nose, being provided with elastic cartilages, are enabled to repeat the part taken by the thorax (§ 739). The nostrils dilate during strong inspiration. Long expiration either retains them in this state, or, if no special voluntary influence co-operates, allows them to return to their earlier condition.

754. Since a powerful respiratory movement requires the assistance of muscles which are attached to very numerous pieces of the skeleton, it

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will not surprise us to find that, if the attitude allows it, almost the whole body moves at this time. In the erect posture, the head, the trunk, and great part of the legs, may be seen to move to and fro during inspiration and expiration.

755. Yawning and hiccough constitute unusual forms of inspiration. The former is a slow inspiration with open mouth or widened nostrils, followed by a shorter expiration: the latter consists of violent impulses produced by abnormal action of the diaphragm.

756. Sighing consists of a vigorous expiration accompanied by a slight sound. In coughing, the movements are similar but stronger; and are accompanied by louder sounds. The power of the expiratory current carries with it the substances present in the trachea, by hawking or coughing; and matters which adhere to the mucous membrane of the nose are similarly removed by hawking or sneezing. The act of gargling is accompanied by repeated expiratory impulses; and laughing is effected by these, with intervening inspirations. The act of weeping, which is distinguished by an increased flow of tears, is usually accompanied by a variety of respiratory movements. The vocal sounds thus presented belong to the expiratory impulses. But protracted weeping leads to sobbing, as a result both of the disturbed inspiration, and of that generally unstrung state of nerves which is one main element of the whole. The sounds which accompany snoring depend upon the vibrations of the walls that limit and enclose the outlets of the respired air; and which are otherwise excited simultaneously.

757. Ordinary inspiration and expiration are accompanied by certain sounds, which are perceived on applying a stethoscope (§ 605) to the thyroid region. Here the air may be heard piping through the narrow glottis. If mucus has accumulated in the air-passages, the altered respiration exhibits a distinct rattle. Finally, the air may resound in those larger cavities which are sometimes morbidly produced in the lungs. Hence the respiratory sounds are frequently examined with a view to the diagnosis of disease.

758. When we strike a solid receiver, the sound varies according to the nature of its contents. Hence percussion informs us of the condition of the thoracic and abdominal viscera. The solid liver gives a dull sound; the stomach replete with gases, a clear one. Similar differences are exhibited by the lungs when abnormally obstructed, or when normally filled with air.

759. The pneumatometer, an instrument corresponding to the hæmadynamometer (§ 86), and provided with a mouth-piece, serves to measure the pressure of the respiratory air. Such an apparatus is represented in Fig. 129. Supposing the person whose lips are pressed air-tight against the mouth-piece, *e*, breathes either solely or chiefly through the mouth, the fluid present in *c* will rise during inspiration, and that in *b* during

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expiration. Doubling this result will give the correct pressure (§ 86). In order to investigate smaller differences of tension, *b c* is filled with water; larger amounts are determined by a mercurial column.

Fig. 129.

760. Ordinary tranquil breathing gives but a small mercurial column for the two opposite respiratory pressures; the normal tension of each being less than one-fifth of an inch. A somewhat more vigorous breathing easily produces one of $\frac{1}{8}$th to $\frac{1}{2}$ inch, or even more. On breathing through the mouth only, the index column rises higher than if part of the air simultaneously passes through the nose.

761. If we make a person inspire as deeply as possible, or expire after distending his chest to the uttermost, we not unfrequently get pressures which considerably exceed the tension of the blood in the carotid. But the state of the person's body exerts an important influence on the result. A weakly youth of somewhat less than middle height, who had formerly suffered from disease of the chest, only raised the mercury ·87 inches during inspiration, and 1·5 during expiration. The highest numbers which I obtained in a series of observations on students amounted to — 9·13 and + 10·24 inches for these acts respectively. A more recent examination gave still greater amounts of expiratory pressure. One young man raised the mercury 10·47, a second 11·58, and a third 12·84 inches. Hutchinson's researches lead him to suppose that the ordinary pressure is about 2·5 inches, and that 10 inches is an extraordinary quantity.

762. Observations made upon thirty-two students showed that the highest expiratory pressure occurred in men distinguished by great muscularity. Only one of them was tall and slender; a second, who also exceeded the average height, and gave 11·58 inches, was remarkable, at a glance, for his strong bones and muscles; the third, who reached 12·84 inches, was short, but so muscular and broad-shouldered that I was enabled to predict a very considerable pressure.

763. Every man can better impel the mercurial column of the pneumatometer upwards by many small shocks, than by one unbroken expiration. In the former case, short movements of inspiration are frequently interposed.

764. The arrangement of the thoracic framework, and the rigidity of

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the bronchial ramifications, (§ 750) is such as to prevent the deepest expiration from expelling all the gases contained in the lungs of a healthy adult. A certain quantity of residual air is always left behind. And on the other hand, the deepest inspiration does not fill the respiratory organs so completely as when they are strongly inflated in the dead body. Hence we see that the maxima of fulness or emptiness found in the dead body—maxima which amount to from 488 to 549 cubic inches—will not apply to the phenomena which occur during life. It is also obvious, that the quantity of residual air present during life cannot be accurately determined.

765. In a vigorous subject the temperature of the lungs amounts to at least 99·5°. The atmosphere which surrounds us is generally much colder. Omitting all consideration of those subordinate differences in the capacity for heat which are produced by the interchange of the gases, it is evident that the air respired at a lower temperature will be more warmed, the longer it remains in the lungs, and the larger the surface of its contact. But from the description already given (§ 725) of the pulmonary structure, we may conclude that this second element increases with the multiplication of the bronchial ramifications, and attains its maximum in the air-cells of the lungs. Even apart from inspiration and expiration, this difference must produce a certain current of air in the interior of the respiratory organs. If the person be standing or sitting, the warmer air of his air-cells will ascend, and the colder air of the trachea and bronchi will descend; just as the greater part of the warm air in a heated chamber seeks the ceiling, while the colder sinks to the ground. Besides this, we shall hereafter find that the circulation of the air is favoured by the formation of vapour in these organs, and even by the interchange of gases.

766. These considerations will enable us to estimate the advantages which the residual air affords. If the gas inspired at one instant were exhaled with the next expiration, the time during which the blood and the air act upon each other would be very short. The residual air prevents this disadvantage. It does not constitute an unchangeable fluid; but only furnishes, as it were, a kind of funded capital, which is raised to a certain amount by the following inspiration. And that circulation of air which has just been mentioned allows the next expiration to drive out, not all the air just inhaled, but only a portion of it: *i. e.*, a mixture of residual and new air. So that we have here an arrangement, by means of which a quantity of the air inhaled remains in the lungs for a longer period than the duration of a single respiration. Hence the three chief changes —the equalization of temperature, the formation of watery vapour, and the interchange of gases,—gain time for a more energetic action. Taking any particular amount of these changes, the residual air will

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allow of its being obtained with a comparatively smaller quantity of air And since the introduction of breathing air is mechanically dependent upon the muscles, this advantage at the same time economizes the expenditure of a certain amount of their contractile force.

767. There are three circumstances which unite to raise the temperature of the cold air of inspiration in the lungs. A certain quantity of oxygen is absorbed by the nutritional fluid and the blood. The condensation which thus occurs sets free a corresponding quantity of heat. The elevation of temperature to which this phenomenon gives rise is the smallest of the three. A certain quantity of carbonic acid, and often also of nitrogen, is given off from the blood. These gases will therefore possess the ordinary temperature of the animal tissues; 99·5°, or somewhat more. But this source of heat is also of subordinate importance. The chief one consists in the fact, that the air, which remains in the lungs longer than a single respiration, (§ 766) tends to acquire a temperature equal to theirs. But since fresh warm blood is constantly flowing through the lungs, these organs themselves are very little cooled. And as fresh quantities of heat are continually furnished, they warm the air more easily. The formation of vapour in the lungs has the contrary effect of lowering the temperature (§ 184).

768. If we examine into these circumstances with the thermometer, we shall find that, in ordinary respiration, the air is exhaled at a temperature of nearly 99·5°, when the external atmosphere has one of 68° : so that the gases of respiration have about the same temperature as the internal organs. Here there is sufficient time to allow of the temperature being equalized. But if we breathe in the cold, the air of respiration exhibits a lower temperature. Thus, at 20·7°, the expired was only 85·6°. We shall see that in this case its real temperature was from 2° to 4° more. But it always remains considerably less than 99·5°. When chilled by long exposure to cold, the temperature of the air we exhale is at first always lower than usual; even though we enter a warm room. While, on the contrary, when I inspired air at 107·4°, I found that of expiration was only heated by the comparatively small quantity which raised it to 100·6°.

769. Assuming that the air inspired at a temperature of 68° is heated to 99·5°, and that at 20·7° to 85·6°, it will follow that the absolute difference is much more considerable for the lower than for the higher degree of heat: the rise of temperature amounting to 65° in the second case, and to only 31·5° in the first.

770. If we breathe on a plate of glass, drops of water are soon deposited on its surface. This simple fact shows that there is a certain quantity of watery vapour contained in the air expired. And the foggy appearance of our breath in cold weather depends upon the cooling which the expired air instantaneously undergoes. This prevents it from

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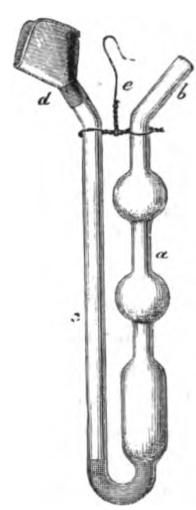
retaining all its watery vapour (§ 191). The fog itself consists of drops of condensed water.

771. If a current of dry air is passed through water, the short time during which the gas remains in the fluid generally suffices to saturate it with vapour corresponding to the temperature. And since the greater part, if not all, of the air inhaled remains in the lungs longer than one respiration, it will necessarily become saturated with watery vapour. This result is greatly favoured by the large moist surface with which the gases come into contact. Ordinary tranquil expiration expels on an average 30·5 cubic inches from the lungs of an adult man. The surface of the bronchial ramifications and pulmonary air-cells may be estimated at 18612·8 square inches,* or even more. Hence, supposing that the gas expired was, in the previous instant, equally divided amongst all the pulmonary cavities, one cubic inch would correspond to 600 square inches of surface of contact. And whether this supposition be correct or not, there is no doubt that the surfaces of contact are very large.

772. We have seen that the saturation of the air with watery vapour essentially depends upon its temperature (§ 191). Taking the barometer at 29·9 inches (§ 188), 61·028 cubic inches of saturated air contain ·6 gr. of water at 96·8°, ·633 at 98·6°, and ·664 at 100·4°. Some observers state, that the expired air is not quite saturated with watery vapour: but in all probability this only depends on their calculations having assumed a constant temperature of 99·5, while the true one was something less. The nature or rapidity of the respiration, which at once rejects a certain quantity of the inhaled air, may perhaps produce similar deviations.

FIG. 130.



773. The tube represented in Fig. 130 forms the simplest means for determining the quantity of water. The glass tube, *c a b*, contains a certain quantity of sulphuric acid, which greedily attracts watery vapour, and leaves the air in a completely dry state. On expiring through the mouthpiece *d*, the increased weight of the apparatus will indicate the quantity of water yielded in the corresponding unit of time.

774. If the temperature be constant, a given quantity of water will, when vaporized, saturate a certain volume of air. Hence this may be determined from the two former, or the temperature may be calculated from the two latter, conditions. And if we know the temperature and cubic contents of a quantity of air, the weight of the vapour it contains will tell us whether it is saturated or not.

* Equivalent to a square which has a side of about 11½ feet.—EDITOR.

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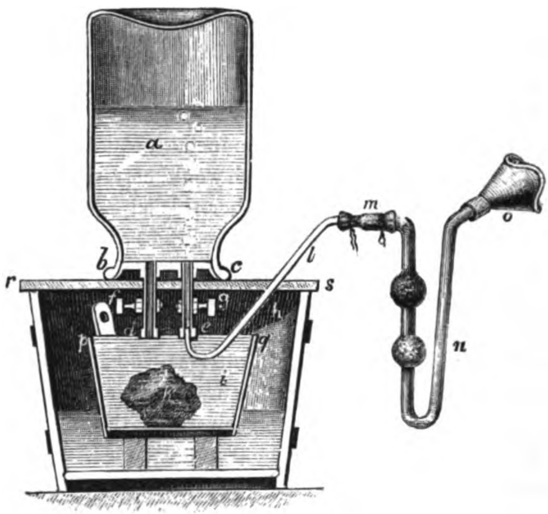
775. The accompanying woodcut (Fig. 131) represents an apparatus, by means of which the conditions just mentioned may be alternately regulated. It constitutes a kind of pneumatic winnowing machine. The gas of respiration passes into the flask *a*, the cubic capacity of which up to a certain line has been previously determined. By breathing through *o*, the air passes through a tube partially filled with sulphuric acid, *n;* where it

FIG. 131.



gives off its water, to be again saturated with watery vapour in *a*. The chief difficulty consists in giving the gas contained in *a* the same temperature as that which it originally possessed,—a condition which can at most only be fulfilled with certainty to about 1°.

The vessel *a*, had a capacity of 446·7 cubic inches, the barometer was at 27·7 inches, and the temperature of the air at 62·6°. And 446·7 cubic inches of the air expired by me contained 4·46 to 4·49 grains of vapour. Saturation at 98·6° would have required 4·26, and at 100·4°, 4·51 grains.

776. Repeating this experiment at the lower temperature of 43·88° to 47·75°, I obtained 3·32 to 3·5 grains. But at the existing pressure of 28·57 in. bar., the temperature of 87·8° to 91·4°, required 3·29 to 3·63. When examined with the thermometer, the expired air had a temperature of only 85·69°. Hence we see that the expired air gives off less vapour in the cold. While the calculation of its temperature from the weight of vapour, would in this case have led to trustworthy results.

777. When a man inhales an absolutely dry atmosphere, it is evident that all the water contained in the air he expires must have been derived from his blood and nutritional fluid. But ordinary air always contains

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watery vapour: being saturated with it for the temperature during rain, and containing a smaller quantity during clear weather. Since the capacity of saturation rises with the temperature (§ 191), the more its warmth is increased in the lungs, the more water will it take up. In these cases, the body does not furnish all the water that is mixed with the exhaled air; but only makes up the quantity of watery vapour required by the rise of temperature.

778. Let us suppose the simplest case,—that the inspired air is saturated for a temperature of 59°, and the expired for 99·5°:—61 cubic inches of the former would therefore contain ·2, and the same quantity of the latter ·664 grains of water. Hence the body must contribute from its own substance ·464 grains for every 61 cubic inches. But if the air inspired were only half saturated, and contained only ·1 grain of watery vapour, the addition would amount to ·564 grains.

779. This fact compels us to be cautious in estimating the quantities of water which are expelled from the lungs. Even supposing that the air always remains in the lungs until completely saturated, still there are other circumstances which exert an important influence on the final result. For we have already seen that it depends upon the warmth of the inspired air how high its temperature is raised, and hence how great is its vaporous content. It is also by no means indifferent whether that quantity of air which corresponds to a given period of time be breathed quickly or slowly, easily or forcibly. And when a man discharges from his lungs 100 grains of watery vapour within a given space of time, if the surrounding air be in a state of absolute dryness, the whole is given off by his organism: while if it be already saturated with vapour, he himself only contributes a minimum. Now since the quantity of water contained in the atmosphere varies from absolute dryness to complete saturation, the quantity really furnished by the organism can only be accurately deduced from an analysis of the air then present.

780. There is a second circumstance which increases the difficulty of determining the absolute quantities of water set free by the lungs in a given space of time. A man who breathes into an apparatus never does so as unconstrainedly as he would in the open air. The consciousness that the results of respiration are being examined, suffices to disturb the rest necessary to a proper play of the breathing. Besides, every apparatus opposes a certain amount of resistance to the transit of the current of air: and the struggle to overcome this, unconsciously increases the activity of the respiration.

781. Since the quantity of watery vapour contained in the expired air has an intimate relation with the volume of the latter, it is evident that it will vary with the bulk of the body. A young man of eighteen and a half years, whose weight was 95 lbs. 15½ ounces, and whose height amounted to 5 feet 1 inch, gave off an average of 3·75 grs. in every

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minute. A second of seventeen and a half years, with a weight of 191 lbs. 15⅙ ounces, and a height of 5 feet 7⅓ inches, gave 8·3 grains. The author, whose weight was 119 lbs. 2¼ ounces, and whose height was 5 feet 3⅓ inches, gave 4·124 grains. This would make 247 grains for every hour, and from 10·6 to 14·12 ounces for the twenty-four hours.

782. The apparatus represented in Fig. 131, p. 238, will also tolerably acquaint us with the quantity of air expired. When the temperature of the air inspired was 59°, and its barometric condition 28·15 inches, the author was able to fill the flask (having a capacity of 446·7 cubic inches) in twelve breaths, which required seventy-one seconds of time. Hence this was about 378·37 cubic inches in the minute, and 7628·5 cubic inches (or somewhat less than 4½ cubic feet) in the hour.

If the temperature of the water be not made exactly equal to that of the expired air which it shuts off, the temperature—and hence the volume—of the latter will be altered during its transmission. If ordinary cold water be made use of, the air is condensed, and occupies less space. This causes too long a time to be taken up in filling the flask, so that the quantity obtained for an unit of time is smaller than it should be. Besides this, the water absorbs a certain quantity of the carbonic acid included in the expired air. While, unless the rise of temperature, and the consequent increase of volume, which the heat of this absorption produces, equal its other diminutions, this will give us a second source of decreased bulk.

783. The whole of these objections are applicable to the similar attempt to determine the quantities of air expelled by an ordinary or extraordinary expiration. Hence though the spirometer which we shall shortly describe, may be useful to the physician,—since the sources of error to which it is liable are but small, when compared with those differences which occur in healthy and diseased persons,—still it does not afford a means of exact scientific investigation.

784. Starting with the supposition, that the air of expiration is saturated with watery vapour for the existing temperature, a simple calculation will give us more satisfactory estimates. The average temperature of the inspired air is from 59° to 64·4°, and the average daily barometric condition 27·82° inches. If I make twelve respirations, I exhale on an average 3·8 grains of water in the minute. This gives 384·48 cubic inches of expired air. If such an estimate is somewhat more than the result previously determined by direct experiment, this depends, partly on the lower state of the barometer, partly on the somewhat higher temperature of the secluding fluid.

785. When the air is warmed in the organs of respiration, it undergoes a direct expansion (§ 195). On taking up watery vapour, its tension rises in a corresponding degree (§ 191); and an additional increase of bulk is the consequence. But if the quantity of oxygen absorbed exceed

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that of the carbonic acid given off, its bulk will be diminished. But we shall see, that, under ordinary circumstances, this diminution does not equal the increase consequent upon the two first causes. Hence the gas expired is more rarified than that inspired.

786. The mode of breathing leads to differences of volume, which are even more considerable than those just mentioned. First as regards the absolute quantities, a deep breath gives off much more than a short one. Forty respirations, made by the author in the minute, gave about 8 cubic inches each, while five gave 90 each: making a total of 320 and 450 cubic inches respectively for this period of time. This advantage of the slower and deeper inspiration is probably due to two causes. The stronger pressure produces a greater velocity. Besides this, less time is wasted.

787. The average quantity of air expelled by an adult man with every tranquil or slightly increased expiration, amounts to about 30·5 cubic inches. If we suppose that the lungs, unrestrained by the walls of the thorax, are capable of enclosing a maximum of 550 cubic inches, this average will amount to about $\frac{1}{18}$th of their capacity.

788. When a person empties his lungs as completely, and then inspires as deeply, as possible, the quantity of air expelled by the subsequent maximum expiration, is called the vital capacity of the lungs; since it forms a tolerable measure of that alteration of their capacity which is possible during life. Other things being equal, the result is determined by the development of the organs of respiration, by the muscular strength and mobility of the several parts of the thorax, and by the way in which the person makes use of the powers at his disposal. If a part of the lung be morbidly obstructed, or destroyed by suppuration, the vital capacity will obviously be rendered smaller; and the diminution of any of the above constituent causes will lead to the same result.

789. The spirometer invented by Hutchinson is represented in Fig. 132. It is a gasometer. The volume of air breathed into it is measured by the scale (15). The tube (14 to 19), serves for expiration. The double tube, (6, 7) contains coloured alcohol, which shows the difference of tension of the internal and external air (§ 86). The thermometer (13) gives the external temperature. When air is impelled into it, the cylinder (20, Fig. 133), rises. The index applied to the scale (15) informs us as to the amount of the vital capacity. If we remove the stopper (17) from the orifice (16), and press the cylinder (20) downwards, the air escapes, and the gasometer returns to its previous condition, as represented in Fig. 132.

But the circumstances mentioned in § 782, added to the inaccuracies which occur in all gasometers, make it evident, that although such an instrument may suffice for the general purposes of a medical examination, it will not afford accurate scientific details.

790. Hutchinson examined 1,923 men, most of them vigorous subjects; and found that the vital capacity varies with the height of the body: the

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volume of air increasing 8 cubic inches for every inch of height.* But the values obtained do not lead to such a simple progression with numerical accuracy. They are as follows:—

Height in Inches.	Average vital capacity in cubic inches, according to Hutchinson.		Height in Inches.	Average vital capacity in cubic inches, according to Hutchinson.	
	Experiment.	Calculation.		Experiment.	Calculation.
60 to 61	174	174	66 to 67	229	222
61 „ 62	177	182	67 „ 68	228	230
62 „ 63	189	190	68 „ 69	237	238
63 „ 64	193	198	69 „ 70	246	246
64 „ 65	201	206	70 „ 71	247	254
65 „ 66	214	214	71 „ 72	259	262

791. Persons whose height is less than five feet, have, on an average, a smaller vital capacity. But there are no extensive statistical researches showing the influence of sex.

792. The age and weight of adults have less influence than their height. The circumference of the chest around the nipples, and the mobility of the ribs, appear to be more important.

793. The chief use of these spirometric researches consists in their enabling us to recognize pulmonary disorganisation. A person in whom a part of the respiratory organs has become impermeable, may exhibit an

* The author adds, that "this has been confirmed by Simon[7]) from a series of examinations, including 93 persons. He finds that the vital capacity increases 9½ cubic inches for each inch of height. His averages are, however, less than Hutchinson's, the difference probably depending upon the fact, that the English observer had the opportunity of observing particularly strong and well nourished men." The following table is reduced from Simon:—

Height in Inches.	Average vital capacity in cubic inches, according to Simon.		Height in Inches.	Average vital capacity in cubic inches, according to Simon.	
	Experiment.	Calculation.		Experiment.	Calculation.
61·4 to 62·4	147·1	147·1	66·3 to 67·3	206·9	192·9
62·4 „ 63·4	169·7	156·2	67·3 „ 68·3	209·3	202·0
63·4 „ 64·4	175·2	165·4	68·3 „ 69·3	223·4	211·2
64·4 „ 65·4	183·1	175·5	69·3 „ 70·3	221·5	220·3
65·4 „ 66·3	195·3	183·7	70·3 „ 71·3	229·5	229·5

The 4500 cases on which Dr. Hutchinson's tables are now founded, could scarcely have been selected for unusual strength or condition: hence one can only suppose that the higher English average depends upon conformation, itself determined by race or climate. As Physician to a Life Assurance Office and an Hospital, I have made hundreds of careful observations with Dr. Hutchinson's instrument, which is an indispensable aid to the early diagnosis of pulmonary disease. From these I incline to think, that Simon's German average approaches nearest to that of the sedentary English citizen. I would further conjecture that, in both tables, the great excess attained by a few athletic individuals has had a disproportionate effect in raising the standard or mean capacity of the whole number.—EDITOR.

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extremely small vital capacity, when as yet no other sign betrays the impending disease. Paralysis of some of the thoracic muscles, or any cause which prevents the thorax from sufficiently altering its volume, will cause similar deficiencies.

FIG. 132.

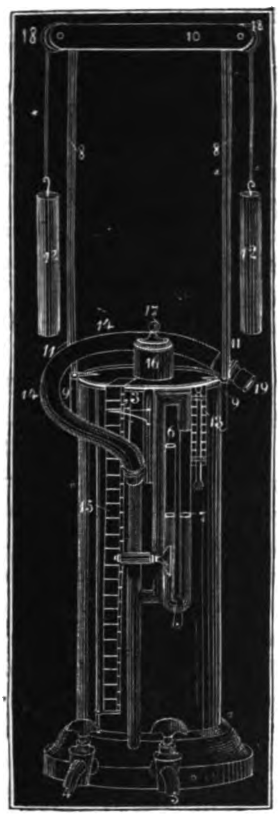
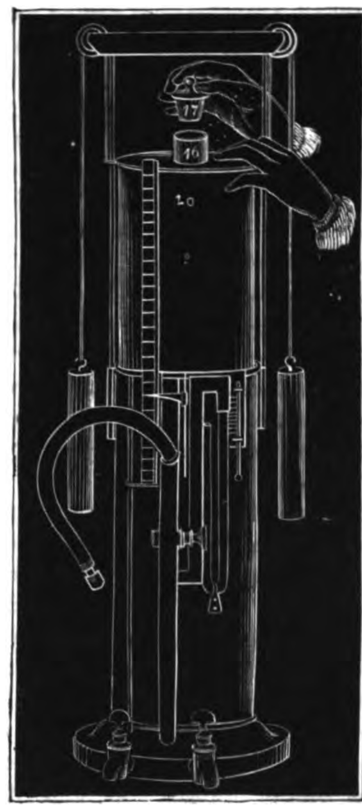


FIG. 133.



794. In the living subject it is impossible to determine the exact fraction of its previous capacity by which the thorax enlarges during the deepest inspiration. Since other fluids enter at the same time (§ 559), the vital capacity does not give the total absolute amount of expansion. Besides this, our ignorance of the capacity of the chest would alone prevent us from reducing the vital capacity to fractions of its original bulk. Hence attention has been limited to mere measurement of the alteration in size undergone by some regions of the chest. From a series of observations of this kind made by me upon the upper part of the præcordia in young men, it results, that the deepest inspiration and expiration causes a difference of from $\frac{1}{7}$ to $\frac{1}{12}$th;—on an average from $\frac{1}{8}$th to $\frac{1}{9}$th.

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The height of the body varied from 56·7 to 68·5 inches. The circumference of the author's chest in the above region amounted to 31·5 inches in the deepest inspiration, and to 27·95 in the strongest expiration: where the difference of 3·5 inches forms a fraction of $\frac{1}{8}$th to $\frac{1}{9}$th of the whole. With a height ranging between 65·74 and 66·93 inches, Simon obtained $\frac{1}{8}$th to $\frac{1}{9}$th, and on an average $\frac{1}{10}$th, for the region of the nipples. Circumstances already mentioned (§ 746) entitle us, *à priori*, to expect, that the change is somewhat less in the upper than in the lower half of the chest.

795. The percentage of every gaseous mixture may be determined from its weight or volume. If the different constituents have a different specific gravity, the two modes of estimation will give different results. By varying the amounts of the gases possessing the greater and lesser specific gravities, results apparently the most contradictory may be obtained for the weights per cent. Since this frequently occurs in the respiration of man, we will represent the whole by a single example.

If we suppose 100 cubic inches of dry atmospheric air to contain 79·06 cubic inches of nitrogen, 20·9 of oxygen, and ·04 of carbonic acid, these numbers will obviously represent the volumes per cent. But 61 cubic inches of nitrogen weigh (at 29·9 in. barometer) 19·4887 grains, while the same bulk of oxygen weighs 22·18 grains, and the same bulk of carbonic acid, 30·5853 grains. Hence, under these circumstances, 100 cubic inches of the mixed gas would contain by weight 76·8 per cent of nitrogen, 23·1 of oxygen, and ·06 of carbonic acid.

If we now imagine 4 cubic inches of carbonic acid added, while 4·7 of oxygen are taken away, the mixture would present 79·06 cubic inches of nitrogen, 16·2 of oxygen, and 4·04 of carbonic acid. We should have a total of 99·3, or a loss of ·7 cubic inches. Reckoning their bulks per cent, we have 79·62 of nitrogen, 16·31 oxygen, and 4·06 carbonic acid. But if we again inquire into their weights, we shall find them 76·1, 17·8, and 6·1 respectively. Hence we see that in the second case the volume per cent of nitrogen rises, while its weight falls. This apparent contradiction is explained by the relation of the diminished volume of the air to the high specific gravity of the carbonic acid. The diminished bulk of the entire mass of air raises the percentage volume of nitrogen, the absolute bulk of which remains unchanged. But the greater specific gravity of the carbonic acid, or the considerable weight of the quantity of it which is already present, so greatly depresses the weight per cent of nitrogen, as to give it a smaller number.

796. In all eudiometric analyses, the oxygen and carbonic acid may be determined by weight or by volume. Since the space occupied by a quantity of air essentially depends upon the temperature (§ 195) and pressure (§ 67), while its weight is not affected by either of these causes, it follows that the measurement of volumes requires many more precau-

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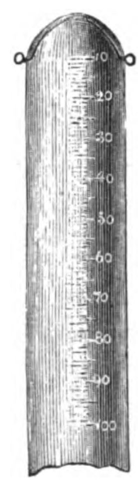
tions than that of weights. If we also consider that the gases of respiration are cooled by their introduction into the measuring tube, and that oxygen possesses a degree of expansion which differs from that of carbonic acid, it will follow that, *cæteris paribus*, weighing is much safer.

797. If the graduated tube be filled with a gaseous mixture containing a certain quantity of carbonic acid, and the whole brought into contact with a solution of caustic potash, lime, or baryta, or with solid potash, the carbonic acid will be absorbed. The loss of volume may therefore serve as a means of estimating the quantity of this gas.

798. We will suppose that the tube represented by Fig. 134 contains atmospheric air, the volume of which may be read off upon the graduated scale. If a certain quantity of hydrogen be added, it will form an explosive mixture with the oxygen of the atmosphere. If the electric spark be now passed through it,—which may be done by discharging a Leyden vial through the platinum wires fixed into the upper part of the jar,—the explosive mixture is converted into vapour, a part of which is usually condensed into drops of water. The diminution of volume certifies the quantity of explosive mixture which has disappeared; and the known composition of water, the quantity of oxygen which is present. The old Voltaic eudiometer was an apparatus which thus determined the quantity of oxygen. But this mode of proceeding was afterwards disused, chiefly because it was remarked that some nitric acid was occasionally produced from the nitrogen and oxygen. And when this was taken up by the drops of water or the secluding mercury, too large a quantity of oxygen was obtained. Bunsen and Regnault have, however, made this experiment the basis of their new eudiometric test.

FIG. 134.



799. A piece of phosphorus has frequently been introduced into the tube represented by Fig. 134, in order to determine the volume of oxygen present. But such very important sources of error are thus met with, as seriously to affect the accuracy of the result. Phosphorus is, however, peculiarly adapted to the determination of oxygen by weight.

Let us suppose that *a*, Fig. 135, is filled with a gaseous mixture of oxygen and carbonic acid:—the remainder of the apparatus may serve to represent the procedure for its analysis by weight. We have first a water eudiometer, *b*; that is, a tube filled with sulphuric acid and asbestos, which takes up the watery vapour contained in the air. At *c* is represented the eudiometer of Brunner, containing warm

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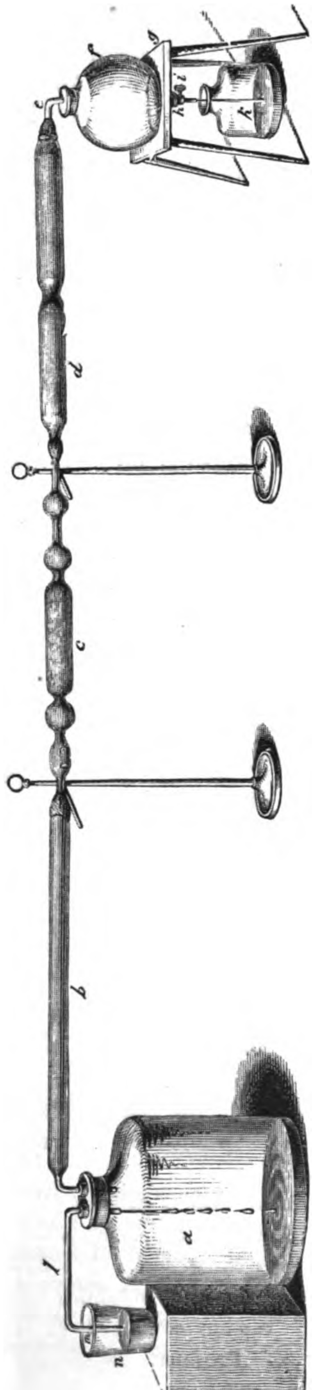

FIG. 135.

phosphorus which possesses itself of all the oxygen. In the eudiometer at *d*, all the carbonic acid is taken up by the lime (saturated with potash) which it contains. Hence it is only the gases and vapours which do not belong to either of the categories just named, which pass into the aspirator, *f*. Disregarding minute admixtures of foreign substances, if atmospheric or expired air be contained in *a*, *f* will receive nitrogen only.

If the whole system of tubes be closed air-tight, as soon as the cock of the aspirator, *h i*, has been opened, a draught begins, so as to allow the oil it contains to flow off at *k*. The siphon, *l*, sucks in from *n* just so much fluid as equals the quantity of gas which the aspiration has removed from *a*, in the direction towards *f*. In order that as little carbonic acid as possible may be thus absorbed, *n* is filled with a saturated solution of salt (§ 150). The oil present at *f* prevents the dry nitrogen which has passed over, from again taking up watery vapour.

The increased weight of *b* informs us as to the quantity of watery vapour contained in the gas present at *a*. But if, at the commencement of the analysis, some solution of salt occupied the bottom of *a*, the air was saturated with watery vapour for the existing temperature. Hence the increase of weight in *b* assists to check the temperature possessed by the gas during the analysis.

The increased weight of *c* gives the quantity of oxygen, and that of *d* the carbonic acid. The mutual proportion of these gases by weight

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is thus obtained by a method which is quite independent of the existing temperature and pressure. But the nitrogen is only given by volume: being the bulk of oil which has run off at *f* towards *k*. We must, therefore, reduce this volume to weight, in order to calculate the percentage weight of the whole. Or, if we desire the volumes per cent, we have but to calculate the space which the weights of oxygen and carbonic acid obtained would occupy at the existing temperature and pressure.

800. From former incomplete eudiometric researches, it was supposed that the atmospheric air contained 21 volumes per cent of nitrogen, and 79 of oxygen. Dumas and Boussingault, who, instead of phosphorus, made use of red-hot shreds of copper, believed that the oxygen was exactly 23 per cent by weight. But later researches indicate that such simple round numbers are not correct.

801. If we disregard the small quantities of carbonic acid which are contained in ordinary air, or remove them by means of a lime eudiometer (§ 799), the percentage of oxygen—according to the latest observations on its weight—will be 20·8 to 20·9 by volume, and 23· to 23·1 by weight. In the observations made by Bunsen and Regnault, electrical combustion gave somewhat higher estimates (§ 798). In these, the volume per cent generally ranged from 20·9 to 21·; without, however, quite reaching the latter number: and the differences of the several analyses were less than in the determination by weight.

802. This example plainly confirms the proposition formerly laid down, (§ 278) that eudiometric researches are more perfect than elementary analyses. The differences in the quantity of oxygen are here as little as $\frac{1}{20}$th to $\frac{1}{5}$th per cent. Still even these small variations are a serious mischief. It is true, that, in inquiring whether the atmosphere offers any noticeable differences in its higher or lower, northern or southern regions, a difference of $\frac{1}{20}$th per cent is comparatively unimportant. But since the portion of air analyzed is inconceivably small in comparison with the total quantity, $\frac{1}{20}$th per cent will greatly affect the absolute amount. The same objection applies to all calculations of the phenomena of respiration for extensive periods of time, such as 24 hours.

803. The carbonic acid of the normal atmosphere forms but ·03 to ·06, on an average ·04, per cent by volume. But when a great number of men or animals are confined in an enclosed space, the proportion rises, on account of the admixture of considerable quantities from the air expired. For example, according to Leblanc, a school contained ·87, and a stable ·22 per cent. The presence of fire, or of fermenting or putrefying substances may also increase the quantity of carbonic acid in a room; and may admix other gases, such as carbonic oxide, carburetted hydrogen, sulphuretted hydrogen, and ammonia. A heated room

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containing many persons occupied in smoking and dissecting corpses, gave ·11 per cent.: and a kitchen filled with numerous fragments of dead bodies from ·18 to ·19. These admixtures are the cause why men who descend into places filled with fermenting wine, fæces, or putrefying corpses, are so frequently in danger of being suffocated.

804. It is evident that, when putrefying substances are present, hydrogen, sulphuretted hydrogen, and volatile organic matters, will be mixed with the atmosphere. Ordinary spring-water and ice generally contain ammonia. But it is very doubtful whether this is the case with the pure air which occupies districts possessing large quantities of water.

805. From what has been previously stated it follows, that the changes which the air undergoes in the lungs are determined by a series of complicated circumstances. And if we add to this, that eudiometric analyses are open to various sources of error, and that the mode of respiration is capable of exerting a remarkable influence on the interchange of gases, we shall scarcely be surprised at the numerous contradictions offered.

806. As regards the general relations of the process, it is obvious that when air is warmed in the lungs, and loaded with watery vapour, it increases in volume. If respiration be confined to its ordinary limits, more oxygen passes into the blood, than carbonic acid out of it. Regnault further states that, in animals, some nitrogen is generally given off by the pulmonary and cutaneous evaporation. Still it amounts to but a very small fraction of the oxygen absorbed.

807. The volume of carbonic acid in the air expired in ordinary respiration ranges between 4 and 4·5 per cent. The average obtained by Vierordt was 4·3, and that found by Brunner and myself was 4·2.

808. The velocity and mode of respiration, the time during which the air remains in the lungs, the pressure at which it is inhaled or expelled, and the foreign admixtures associated with it,—are all capable of affecting the quantities of carbonic acid. But it has hitherto been found impossible to investigate the influence of all these various causes in accurate detail.

809. When the number of respirations per minute is increased, the percentage of carbonic acid is diminished. It may thus gradually descend to 2·9 and even 2·4 per cent. While conversely, by inspiring and expiring very deeply and slowly, it may be raised to 6. If the lungs be distended to their utmost, and the breath retained until oppression begins to be felt, and if the air be then expelled with a forcible pressure, we shall not unfrequently find between 7 and 8 parts per cent.

810. From observations undertaken with this purpose, Vierordt concludes that—other things being equal—the percentage of carbonic acid for any rapidity of breathing may be reduced to a constant mathematical expression, which is the sum of two members. Of these, one forms a magnitude which is constant for every velocity of breathing; the other is

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the product of the smallest possible average duration, by the given average of each respiration in the particular case.[28])

811. If the air given out at the commencement of a deep expiration, and that finally expelled by its forcible pressure, be each collected in separate receivers, it will be found that the latter gaseous mixture contains more carbonic acid than the former. This phenomenon is explained by two circumstances. The deeper the air penetrates the bronchial ramifications, the more extensive is the surface with which it comes into contact. And since the greater part of the air contained in the air-cells remains in the lungs for a period longer than one respiration, the deep expiration finally expels air which is more completely changed.

812. The carbonic acid is increased during the period of digestion, as well as during violent bodily exertion. On the other hand, it is diminished by the use of tea, or of alcoholic drinks. We have already seen (§ 341) that a portion of this alcohol can pass off in the form of vapour with the air expired.

813. Other circumstances being equal, the proportion which the carbonic acid given out bears to the oxygen absorbed, depends on the kind of respiratory movement. The time during which the air remains in the lungs, the admixture of completely and incompletely respired gases expelled by each expiration, and the pressure exerted upon the chest, will all assist to determine the result.

814. On breathing with short, quick, and irregular pants, I found that the carbonic acid given off exceeded the oxygen absorbed. The volumes of the former were to those of the latter as from 1 to 1·15—·94, and the weights as from 1 to ·83—·68. Hence we see that increasing the velocity of breathing finally causes fewer cubic inches of oxygen to disappear, than are added of carbonic acid. So that if the proportion of nitrogen be nearly or quite unaltered, this would give us a new cause for increased volume of the expired air (§ 785).

While conversely, on inhaling deeply, and then expelling the air by a forcible pressure, the carbonic acid given out was to the oxygen taken in, as 1 to 1·21—1·31 by volume, and 1 to ·87—·95 by weight.

When I filled the lungs to their utmost by a strong inspiration, and after waiting till the commencement of the respiratory anguish, expelled the air under a somewhat increased pressure, they were to each other as from 1 to 1·18—1·22 by volume, and from 1 to ·85—·88 by weight.

815. In the earlier researches of Brunner and myself on respiration, we had remarked, that the relative quantities of oxygen and carbonic acid furnished by ordinary respiration approximate,—within certain limits attributable to errors of experiment—to those which would be required by the law of diffusion; although this proportion is partially interfered with by other conditions—such as the solution of the gases in the blood,

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and the inequality of pressure in the organs of respiration. The law of diffusion, which demands the interchange of gases in proportions inversely as the square roots of their respective densities, would require 1 to 1·176 by volume, and 1 to ·85 by weight. Five subsequent analyses of my breath,—in which all unusual pressure and irregularity of respiratory movement had been as much as possible avoided—gave from 1 to 1·112—1·190: on an average 1 to 1·153. Thirteen analyses of the breath of myself and eight other persons, gave from 1 to 1·141—1·240: on an average, 1 to 1·187.

This correspondence with the diffusive quantities rests upon the mere comparison of the numbers found, and not, as has been frequently stated, upon any theory. Nor do the proportions above mentioned justify the conclusion, that a constant mutual relation of oxygen and carbonic acid can be deduced from my experiments. They rather indicate that sensible differences may be produced by too short a sojourn of the air in the lungs; and by increased pressure.

816. If the air is detained in the organs of respiration, the percentage of oxygen absorbed, and of carbonic acid given off, certainly rises. But on examining the time demanded for this, we find that the amount of change occurring in a given unit of time is less than in the regular and shorter respirations. If the air contained in the lungs is not changed, the amount of the gaseous exchange in a given time constantly diminishes. Its diminution is greater, the more the previous times have already affected it. Vierordt, who discovered this law for the carbonic acid, expressed it by the statement, that the carbonic acid given off from the blood, and contained in the lungs, were in inverse proportion to each other.

817. Earlier observers thought that considerable quantities of nitrogen were given off, or taken up. But later researches on human respiration indicate that this gas undergoes no change which exceeds the limits of errors of observation; and that its variations, when they occur, are scarcely ·3 per cent (or $\frac{1}{80}$th) of the oxygen absorbed. From their observations on animals, Regnault and Reiset state, that, under ordinary circumstances of diet, nitrogen is given off. But it never amounts to $\frac{1}{50}$th of the oxygen consumed, and is generally even less than $\frac{1}{100}$th. According to these observers, fasting birds may also take up small quantities of nitrogen. But in mammalia this phenomenon very rarely occurs. Barral also concludes that small quantities of nitrogen are expelled in the human breath.

818. The breath sometimes contains volatile organic matters. But carbonic oxide and carburetted hydrogen are not found in it. And it may be questioned whether, under normal circumstances, any trace of ammonia is present.

819. It has hitherto been found impossible to establish a satisfactory

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theory of that gaseous interchange which occurs in the lungs. According to Vierordt, who mainly rests upon the law of Dalton (§ 153), carbonic acid is given off from the blood, until the pressure of the carbonic acid in the respiratory air equals that under which it exists in the blood. Something similar occurs with the nitrogen. The oxygen, which is subject to the same law, has, in addition, a great affinity for certain constituents of the blood. It is therefore taken up in more considerable quantity.

We have seen (§ 153) that, according to the Daltonian law, the pressure of a gas essentially depends upon the mixture of which it is composed. Hence if we make an animal breathe any other than atmospheric air, its gaseous exchange ought to be essentially altered. But, on the contrary, Regnault and Reiset found that the secretion of nitrogen remained the same, when the animal occupied a space containing twice or thrice as much oxygen as the atmosphere. Even when the nitrogen of the atmosphere was replaced by hydrogen, the most that could be seen was a somewhat greater absorption of oxygen: in other respects the interchange of gases remained unaltered.

820. It has often been attempted to start from a purely chemical point of view. According to this, the blood, the constituents of which vary with the circumstances of nutrition, will take up as much oxygen as its nature allows. An increase or diminution of the products of combustion will assist to determine the quantity of carbonic acid given off. Nitrogen will be given off or taken up, according as the animal is in a fasting state, or eats a food which is rich or poor in this element.

There is no doubt that these chemical causes exert an important influence upon the absolute quantities of carbonic acid given off. But at present we are utterly devoid of any clue by which we might follow this idea into detail, and thus render it really fruitful. Reference has chiefly been made to the products obtained from carnivorous or herbivorous animals, either during fasting, or after the use of certain kinds of food. But apart from the fact that old and new observations exhibit numerous contradictions in this respect, we shall find, in treating of cutaneous evaporation, that the gaseous mixture which is given off by an animal subjected to a general examination, may be determined by causes other than the function of the lungs and the skin. Such theoretical views can only be based on experiments instituted by some experienced observer upon himself, in which he could accurately compare the influence of the respiratory movements, and of other collateral causes.

821. We have seen that every man who breathes into an apparatus with the necessary care, involuntarily oversteps the ordinary tranquil mode of respiration. Hence almost all such estimates of the absolute quantities of oxygen and carbonic acid are somewhat greater than those of an unconstrained and unwatched respiration.

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822. The most complete series of researches on the quantities of carbonic acid given off are those of Andral and Gavarret. They found that the absolute amount rises from 8 to 40 years of age; and that in old age, and sometimes even earlier, it is diminished: while it is visibly increased by a robust frame of body, by the time of digestion, and by muscular movement.

Confining their attention to its average quantity per hour, they find that a boy of eight years gives off 283 and one of ten years 385 grains. Men of from 16 to 60 years gave 482 to 771 grains; and old men between the ages of 76 and 102, 334 to 499. Brunner obtained 493 at 47, and I found 604 at 33, years of age.

823. In general, the female excretes less carbonic acid than the male. Andral and Gavarret also remarked, that the quantities remain nearer to those of childhood during the menstrual period of life. It is increased when menstruation is absent, or is interrupted by pregnancy. Hannover also found, that chlorotic subjects exhale more carbonic acid than healthy ones.

Healthy girls, from 10 to 15½ years, offered 340 to 402 grains as the quantity per hour. Women between 15 and 45, menstruating regularly, 340 to 397 grains: while those between 38 and 66, in whom the menses had ceased, gave 385 to 561 grains.

824. The author's body, weighing 119 lbs., gave off, on an average, 604 grains of carbonic acid per hour, while the oxygen taken up amounted to 520 grains. Hence 1 lb. of its weight corresponded to 5·068 grains of carbonic acid given off, and to 4·368 of oxygen consumed.

825. The scarlet colour conferred on the dark-red venous blood in the capillaries of the lungs, is due to the action of the oxygen contained in the respired air. But future researches must accurately determine the details of this process. The redness of the blood is chiefly, if not exclusively, dependent on its corpuscles. We may therefore conclude, that the more visible of its respiratory changes occur in these structures. But the facts rather indicate, that the gases concerned in respiration make use of the liquor sanguinis as the immediate channel of their entry or egress. For it is probable that a part of the carbonic acid, nitrogen, and oxygen, is dissolved in the plasma of the blood. Hence it would seem that this fluid has a double action; one outwards on the respiratory air, and one—as it were—inwards on the large total surface of the blood-corpuscles (§ 31).

826. Putting out of consideration that kind of suffocation which is caused by a sudden check of all the respiratory movements, and to which we shall hereafter return in speaking of the nervous system, all other instances of death by suffocation are due to the fact, that the air contained in the lungs is such as to render the normal interchange of gases impossible. For the first condition of this is a certain quantity of free oxygen. Hence an atmosphere consisting only of nitrogen, or of a gaseous mixture which contains no oxygen, cannot support life. Many gases and vapours,—such as hydrogen, chlorine, iodine, bromine, or sul-

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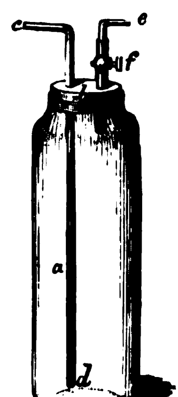
phuretted hydrogen,—are more speedily hurtful than nitrogen. These more injurious consequences are possibly due to their quicker transit into the blood, and to the chemical influences which they probably exert upon the blood-corpuscles.

Suffocation is sometimes induced by large quantities of carbonic acid, or by smaller amounts of carburetted hydrogen. Hence an animal breathing in a confined space prepares the poison which endangers its own life. Or if the outlet of the respiratory organs be occluded by hanging, or by a mechanical closure of the glottis, the air contained in the lungs loads itself with a continually increasing quantity of carbonic acid. The following succession of symptoms then precedes death:—dyspnœa, violent but useless respiratory movements, a darker coloration of the whole blood, blueness of all the transparent cutaneous vessels, over-distension of the soft tissues of the head with dark blood, expulsion of foam from the mouth, flashing of sparks or appearance of darkness before the eyes, giddiness, unconsciousness, spasm of the facial and lingual muscles, general convulsions, and sometimes, priapism and emission in the male, or distension of the clitoris and internal labia of the female. The danger produced by glowing charcoal does not depend upon the carbonic acid alone, but also upon the carbonic oxide and carburetted hydrogen of the air inspired.

827. The removal of the mechanical obstruction, and the inhalation of fresh air, often conquer the most threatening symptoms in a short time. If any small mammal, such as a young guinea-pig, be placed in a vessel like Fig. 136; and if the cover, *b*, be shut air-tight, while the tube, *c d*, is united with an aspirator in a state of rest, and the cock, *f*, is shut; the animal soon exhibits abdominal respiration, followed by convulsions. But even when lying apparently dead, it may soon be recovered by opening *f*, and setting the aspirator to work, so as to allow the transmission of a stream of air from *c d* towards *e f*.

FIG. 136.



828. Many elastic fluids, such as ammonia, produce specific poisonous effects. Still the inspiration of this gas may assist to overcome the dangerous effects produced by the entry of other poisons, such as cyanogen. Certain gases, such as protoxide of nitrogen, make the respiration more rapid; provided they are not mixed with too large a quantity of common air. According to Zimmermann, animals placed in such a gaseous mixture give off more carbonic acid, and take up more oxygen. The results of inhaling the vapours of æther and chloroform will occupy our special attention in treating of the nervous system.

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CHAPTER X.

EVAPORATION.

829. The levelling of differences in temperature, the formation of watery vapour, and the mutual interchange of gases, are phenomena which occur on all the external and internal surfaces surrounded by aeriform bodies. Hence, far from forming any exclusive characteristic of the organs of respiration, they are repeated, with certain modifications for varying collateral circumstances, in the skin, the conjunctiva of the eye, the external auditory meatus, the cavity of the tympanum, the Eustachian tubes, the cavity of the mouth, the other cavities of the alimentary canal, and the vagina. The nature of the intestinal gases (§ 492) depends upon the operation of these processes, in conjunction with the spontaneous decomposition of the relics of the food.

830. The external integument enjoys a twofold advantage. The extent of its surface multiplies the points of contact. Besides this, it impinges upon masses of air which are easily exchanged with, and replaced by, other portions as yet unaltered. On this account, we especially speak of the cutaneous evaporation; and of that pulmonary evaporation which is effected by the respiratory organs. The union of these two forms the total evaporation, perspiration, or transpiration.

831. In animals this total amount has been determined by an eudiometric analysis of the gaseous mixture which the creature has breathed during some time. One method of experimenting may be illustrated by Fig. 137. The cat is enclosed in an air-tight receiver, *h*. One of the two outlets, *o*, leads to the tube of water, *p*, the carbonic apparatus, *f*, the oxygen eudiometer, *e*, and the aspirator, *a*; while the second, *n*, leads to the siphon, *q*, which sucks in a compensating saline solution from the dish, *r*, (§ 799). In this way we get the percentage composition by weight or volume (§ 795) of the air in *h*, which has been altered by evaporation. Knowing the capacity of *h*, and the time during which the animal has occupied the receiver, the corresponding absolute values (§ 822) may be easily calculated.

832. But this mode of experimenting leads to serious inconvenience. The animal must repeatedly inspire and expire the same air, which thus gradually becomes loaded with carbonic acid. This produces irregular respiratory movements, and endangers suffocation, or even death, if the observation be continued too long. The operation is performed under

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abnormal circumstances, the occurrence of which cannot be recognized with certainty.

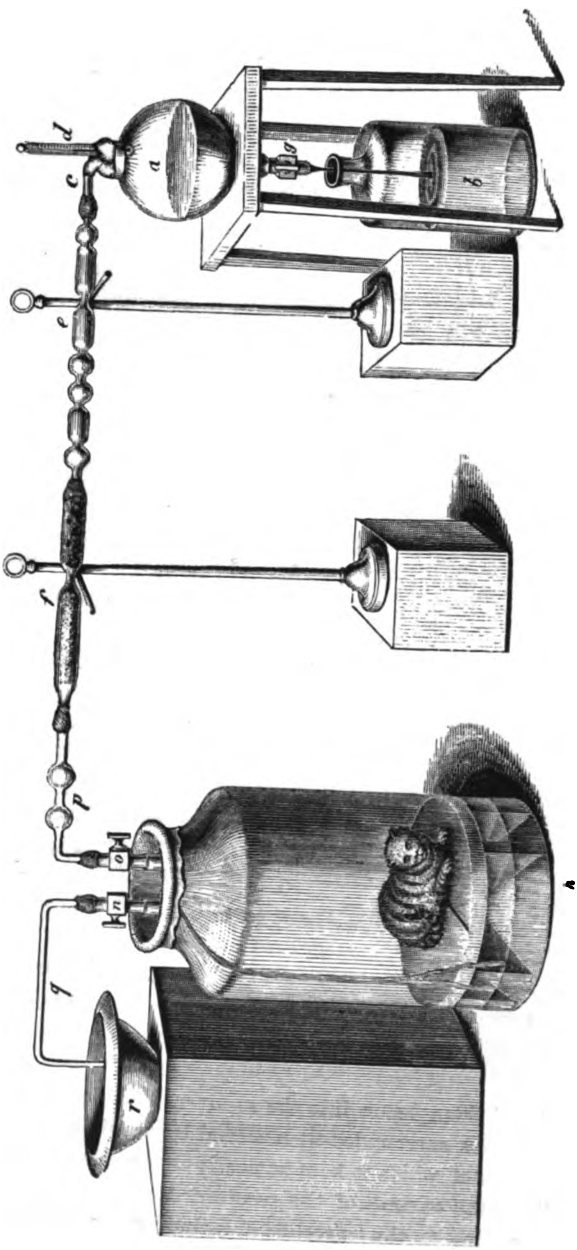

Fig. 137.

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833. Regnault and Reiset endeavoured to avoid this obstacle by at once driving off the carbonic acid, and adding new oxygen. The apparatus made use of for this purpose with larger animals is shown by Fig. 138. The dog

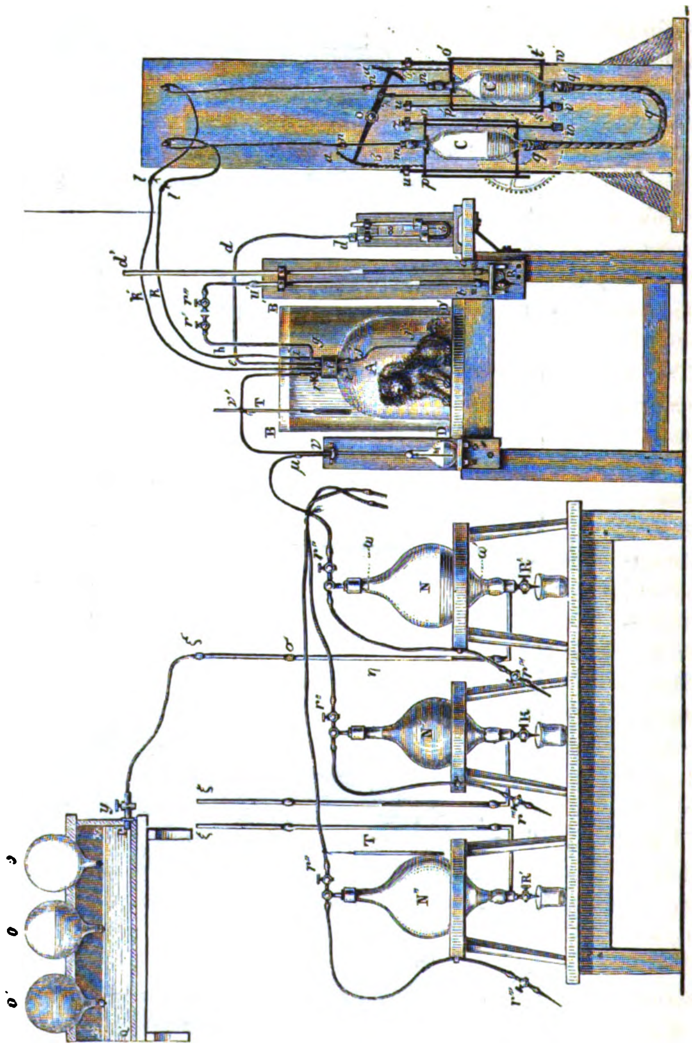

Fig. 138.

is introduced from below into the receiver, A, which can be hermetically closed. This is surrounded by a second larger glass receiver, B B′, D D′, filled with water, which is kept as nearly as possible at the same temperature. Thus the warmth of the receiver, A, cannot vary in any considerable degree during the experiment. One of the tubes of exit, *f e d*, is united with the manometer, *a b c*, which shows the internal atmospheric

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tension (§ 83 *et seq.*). And $g\,h\,r'$ may be united with the manometer apparatus, $r''\,a'\,b'\,c'\,d'$; so that when the gas attains a higher pressure, part of it can be carried over for further eudiometric analysis.

The two vessels, C C′, are connected with $i'''\,i'\,k'\,l'$ and $j''\,g'\,i\,k\,l$: they contain certain quantities of solution of potash, the carbonic contents of which have been previously determined. They are united by means of an elastic tube, $q\,q''\,q'$, and are moved up and down by clock-work. If C′ be down, and C up, the former contains solution of potash, and the latter, air. While, *vice versâ*, when C′ occupies the lowest point, it takes up the alkaline solution, and impels the air, deprived of its carbonic acid, back again into the receiver, A, (Fig. 157). But since the connecting tube of C′ opens high up into the receiver, and that of C low down, this alternate play withdraws the greatest part of the expired carbonic acid from the different parts of the space in which the animal is confined.

The diminished volume of air thus produced causes new oxygen to enter from N. It comes through $r''\,\mu$, passes through a solution of potash at M, and then flows onwards through $v\,v'\,r$. A saturated solution of chloride of calcium, which is present in $o\,o'\,o''$ and $x\,x'$ Q′ P′, replaces the oxygen that passes over through $y\,\xi\,\sigma\,\eta$.

834. In this apparatus animals may spend days, so that large quantities of oxygen and carbonic acid appear in the results. They consume the food introduced with them, and are quite well after the experiment. Still it may be doubted whether the results thus obtained exactly correspond with the normal conditions.

For even supposing that all succeeds so perfectly as to allow of no important objection on the physico-chemical side, there remain some subordinate obstacles, as well as others which seriously affect the physiological side of the question. The recent urine of many animals gives off carbonic acid. The proportion of fæces has not yet been accurately determined. Still these two sources of error are so inconsiderable that Regnault and Reiset did not perceive any serious disturbances thus produced. The same statement applies to the intestinal gases which are from time to time set free.

The way in which the animals breathe exercises a greater influence. A creature which, for many hours and even days, is in a continual current of an air that is somewhat richer in carbonic acid, must breathe differently from what it would in a quiet atmosphere. It is probable that, under these circumstances, the mechanism of respiration—which exerts a visible influence upon the quantities of carbonic acid (§ 814)—is altered in accordance with the structure of the thorax, and its other corresponding arrangements. The fact that the animals seem in perfect health is not opposed to this conjecture. If dogs, rabbits, or mice, be exposed to a current of pure air conducted through the receiver by means of the

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aspirator (Fig. 155, p. 267), they exhibit, after some time, abnormal respiratory movements. It is true that mice and rabbits will feed in spite of this. But a patient suffering from asthma or emphysema often breathes most painfully for weeks and months, without losing either the want of food or the chance of recovery.

Hence it is evident that the more delicate of these questions can only be decided by researches on the human subject. The most delicate point, the influence of the kind of breathing, will only be explained by the experiments of practised inquirers upon themselves.

835. The skin, which generally has a higher temperature than the atmosphere, warms its neighbouring strata as far as their interchange with each other will allow (§ 200). And at the same time, watery vapour, which easily penetrates the dry cuticle (§ 148), is poured out from the nutritive fluid and the blood. Its quantity will vary with the saturation and temperature of the surrounding atmosphere, as well as with the physical characters of the skin, and the amount of blood it contains.

836. Experiments by the author on himself gave an average of 2 lbs. $7\frac{1}{3}$ oz. to 2 lbs. $8\frac{2}{3}$ oz. of water, as given off by the pulmonary and cutaneous evaporation of his body (weighing from 119 lbs. $2\frac{1}{4}$ oz. to 114 lbs. $11\frac{2}{3}$ oz.) in the 24 hours. Barral[29]), who weighed 104 lbs. 8 oz., concluded that the quantity of water given off by him daily was from 2 lbs. $8\frac{1}{3}$ oz. to 2 lbs. $13\frac{1}{2}$ oz. My estimate includes the carbon of the cutaneous exhalation, together with the intestinal gases, the sebaceous secretion of the skin, and the casual fluids of the mouth. With the exception of the carbon, Barral's numbers include the same excretions.

837. Since the watery vapour of the respired air seems to amount to less than 1 lb., (§ 781) it follows that the skin gives off more water than the lungs. This fact may probably be explained by the physical properties of the tissue itself, (§ 148) as well as by the more rapid and free interchange of the air in contact with it.

838. A small part of this vapour depends upon the direct evaporation of water contained in the walls and cavities of the cutaneous glands (Tab. IV., Fig. 63, *i h k*) and hair-follicles (Tab. IV., Fig. 63, *g*). But the greater part of it comes from the moister strata of the cuticle, the highly moistened corium, and its blood. Hence, in order to become free (§ 126) it has to transude the dryer hygroscopic layers of cuticle.

839. Since the quantity of water vaporized within a given space of time depends upon the condition and change of the atmosphere, it not unfrequently happens that the organism gives off more than is immediately volatilized. In this case the skin is covered with separate drops of sweat, which gradually run together. The details of this phenomenon will again occupy our attention in the study of secretion.

840. The simplest general view of the results afforded by late researches on the interchange of the gases in different animals, is obtained

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by bringing together the quantities per hour in proportion to a pound of corporeal weight, and by contrasting the weight of oxygen absorbed with that of carbonic acid given off. Regnault and Reiset assume the specific gravity of the living animal equal to that of water; to which I have, for the sake of comparison, reduced Erlach's estimates. The following are the results:—(See next page.)

Although Erlach's experiments were made in the confined space described in § 831, which only permits short periods of observation, still in most of the animals which can be compared, his limits of the absolute and relative quantities of carbonic acid approach those of Regnault and Reiset (§ 833). And we meet with corresponding variations, which cannot be reduced to any definite laws. This is a further indication that the mode of breathing, which cannot be closely followed, is an important element of the final result.

841. Animals in great want of air give off larger absolute quantities of carbonic acid. Animals of very small size, such as mice, finches, and sparrows, furnish much more carbonic acid than those of greater bulk. The cause of this phenomenon will be explained in treating of animal heat.

842. Mammals and birds take up by far the greater quantity of oxygen in their lungs: and it is here also that they give off most of their carbonic acid. According to Regnault and Reiset, the quantity of the latter furnished by the skin and intestine rarely amounts to $\frac{1}{50}$th of that given off by the lungs. On the other hand, in frogs, the cutaneous transpiration plays the most important part. For a long time, the removal of the lungs does not halve the quantity of carbonic acid per hour.

843. As regards the human subject, Scharling and Hannover found that the adult male gives off, hourly, from 3·13 to 4·14 grs. of carbonic acid for every pound of bodily weight. A woman gave 3·16, and two children 5·82 and 6·33 grs.

844. Comparing these with the numbers quoted at § 840, it follows that the adult man gives off less carbonic acid than any of the mammals there indicated. A chief cause of this difference probably lies in the greater size of his body. Besides this, it must not be overlooked that persons subjected to experiment generally breathe more quietly than these animals (§ 832). Bearing this in mind, we can also understand why the numbers obtained by Scharling and Hannover for the total cutaneous transpiration are less than those found by Andral and Gavarret, Brunner, and myself, for the pulmonary function only. The increase in the latter case was caused by the use of a special apparatus (§ 780) for breathing, which was absent in Scharling's and Hannover's researches.

845. The observations made by Scharling prove that the cutaneous transpiration alone carries off but a small quantity of carbonic acid. Its amount is from $\frac{1}{28}$th to $\frac{1}{52}$nd of the quantity given off in the lungs. Hence the skin is chiefly occupied with the copious evolution of watery vapour.

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According to Erlach.					According to Regnault and Reiset.				
Animal.	Average weight of body in oz.	Hourly quantity in grains of Carbonic Acid per pound of bodily weight.	Weight of Carbonic Acid to that of Oxygen as 1.	Number of Observations.	Animal.	Average weight of body in oz.	Hourly quantity in grains of Carbonic Acid per pound of bodily weight.	Weight of. Carbonic Acid to that of Oxygen as 1.	Number of Observations.
Young Dogs .	18·18 to 33·3	6·01 to 10·25	1·023 to 1·084	3	Dogs . . .	166·34 to 225·68	6·3 to 12·16	·952 to 1·296	12
Young Cats .	28·	5·74 „ 13·59	1·022 „ 1·150	4	Rabbits . .	81·65 „ 146·14	4·76 „ 9·79	·925 „ 1·371	11
Small Rabbits .	5·85 „ 12·08	6·98 „ 15·21	·909 „ 1·272	5	Fowls . . .	30·04 „ 71·31	5·719 „ 14·05	·862 „ 1·472	16
A Guinea-pig before and after parturition . .	12·67 „ 16·98	7·67	1·239 „ 1·427	4	Ducks . . .	40· „ 51·47	9·142 „ 15·96	·857 „ 1·227	5
					Greenfinches .	·618 „ ·88	64·68 „ 98·05	·95 „ 1·043	3
Male Guinea-pig	19·98	7·09	1·357	1	Crossbill . .	1·01	84·224	1·096	1
New born Guinea-pig	2·15	17·6 „ 30·04	1·049 „ 1·682	6	Sparrow . .	·776	73·36	1·093	1
Squirrel (in active movement)	10·31	17·51 „ 26·8	1·018 „ 1·462	3	Frogs . . .	1·32 „ 2·47	·427 „ ·77	·86 „ 1·033	5
Mouse . . .	·388	80·92 „ 91·71	1·132 „ 1·135	2	Frogs with excised lungs	2·03 „ 3·27	·343 „ ·504	1·052 „ 1·094	2
Very young Chickens	11·12	17·31 „ 24·37	1·191 „ 1·324	6					
House-pigeon .	12·48	6·16 „ 17·59	·893 „ 1·37	6					
Frogs . . .	·388 „ 2·12	·504 „ 1·25	1·032 to 1·263	5					

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846. Hitherto no attempt has been made directly to determine the total quantity of oxygen consumed, and carbonic acid given off, in the pulmonary and cutaneous transpiration of the human subject. But indirectly, they have been determined by Barral, from statistical researches which will be hereafter referred to in treating of nutrition. Still these are necessarily an unsafe basis (§ 286). And if, from the absolute values given by this inquirer, we calculate the elementary composition per cent of the solid residuum of the urine and fæces, we shall find that it is the same for all the persons referred to. Hence it is probable that these percentages are not the results of special examinations, but have been reduced from one chief analysis. But since the various kinds of food produce differences in the quality of the urine and fæces, a new and important source of error is thus opened up.

We may collect the estimates given by Barral as follows :—

Person, Age, and Bodily Weight.	Quantity in Twenty-four hours expressed in ounces.		Weight of Carbonic Acid to that of Oxygen as 1.
	Oxygen consumed.	Carbonic Acid given off.	
Barral himself, 29 years, 104·8 lbs.	37·47	43·45	1·16
The same	27·3	31·36	1·15
Male, 59 years, 129·5 lbs. .	31·39	38·42	1·23
Female, 32 " 135· " .	31·3	35·54	1·14
Boy, 6 " 33·1 " .	14·95	18·07	1·21

The average was 1·17, which almost exactly corresponds with the diffusive proportion (§ 815). But the reasons above mentioned prevent us from regarding these numbers as a confirmation of any theory.

847. Supposing that the somewhat forced respiration in my experiments about made up for the small quantity of carbonic acid in the cutaneous exhalation, it would follow that, on an average, I take up 28·52 oz. of oxygen, and give off 33·16 oz. of carbonic acid, in the 24 hours. Here the relative weight is 1·16.

848. Recent eudiometric researches have not proved that any considerable quantities of other gases escape through the skin. Volatile organic matters, and even traces of inorganic compounds, frequently appear. The acid smell generally diffused by a perspiring portion of skin appears chiefly due to volatile fatty acids; as, for instance, caprylic acid (§ 310). The sebaceous secretion of the skin, and the sweat, can furnish abundance of the requisite materials.

849. The function of the skin is capable of being, to a certain extent, inverted by a water-bath. The surrounding liquid not merely hinders or restricts the interchange of air: it gradually soaks through the cuticle (§ 120) and thus allows of endosmose (§ 129). In this way the materials of the bath reach the nutritive fluid and the blood.

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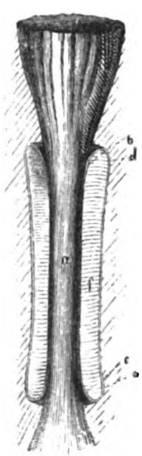
CHAPTER XI.

SECRETION.

850. The porous walls of the vessels permit a reciprocal diffusive current between the blood, which is propelled under a certain pressure, and the nutritional fluid, which soaks the tissues. If the vessels occupy structures which abut on a cavity shut off from the outer air, they will give off fluids, until the tension of these forms a counterpoise to that of their blood, and the chemical attractions are satisfied. This simplest form of secretion obtains in the membranes of the brain and spinal cord, the pericardium, the pleura, the peritoneum, the vaginal tunic of the testicle, the synovial membranes of the joints, the sheaths of the tendons, and the bursæ mucosæ:—in short, in all the serous membranes, and their congeners. The relations of a tendinous sheath are exhibited in Fig. 139. Let *a* be a tendon, the surface of which is covered by the membranous layer *b c*, reflected into the free lamella, *d e*. The blood circulating in *d e* will fill the cavity, *f*, with fluids, until all active difference of pressure or chemical composition ceases. And if any collateral cause alters the fluid contained in *f*, the portions of blood circulating in the neighbouring vessels are always ready to equalize the difference.

Fig. 139.



851. If the cavity that bounds the secreting membrane is open towards one side, the exsudation may be carried off or excreted. This absence of the counter-pressure which finally checks secretion in the closed cavity, ensures its unobstructed continuance in the open one. The skin, the mucous membranes, and the numerous secreting glands, all possess this important advantage. For instance, the bile furnished by the liver (*a*, Fig. 75, p. 132) flows through the hepatic and biliary duct (*n* and *r*) into the duodenum (*i*). In this way the mixture already produced is no obstacle to subsequent secretion.

852. Other circumstances being equal, the quantity of fluid which passes off in a given unit of time must vary with the size of the free surface. Hence nature increases this as much as possible. The structure of the secreting glands may in great part be thus explained.

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853. Let us suppose *a b*, Fig. 140, to be the transverse section of a plane limitary surface; if we roll up *a b* into *c d e*, or fold it into *f g h i k*, its superficies will remain the same. But in the two latter cases the membrane possessing the surface occupies a smaller space. So that if this suffice to the object of the whole, it will be possible to compress an active surface of great extent into a very small organ.

Fig. 140.

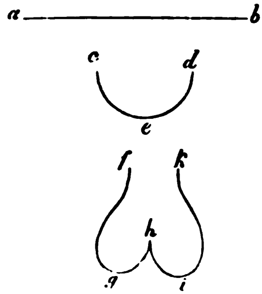
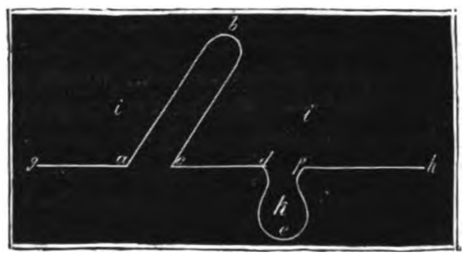


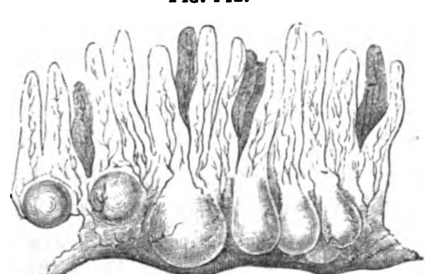
Fig. 141.



854. The secreting membrane, *g b*, Fig. 141, may thus gain surface in two ways. If it expands into folds, villi, or other prominences (*a b c*), these will form a new mass, the interior of which may be occupied by blood-vessels. But the free surface, *a b c*, exceeds the rectilineal one, *a c*, by a certain amount, varying with its form. And its secretion passes immediately into the neighbouring space at *i*. On the other hand, if *g h* sinks into a depression, *d e f*, the mere increase of surface is repeated; but we obtain a follicle, which secretes its exsudation, first into *k*, and thence into the neighbouring space, *i*. The first case represents a simple secretion; the second a secretion, followed by an excretion.

855. And just as gills increase the respiratory surface by external ramifications, and lungs by internal cavities (§ 725), so something like this is repeated in the organs of secretion. The mucous membrane of the small

Fig. 142.



intestine is studded by numerous villi, such as are represented in Fig. 142. These increase the secretion of intestinal mucus, as well as the capacity

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for absorption. A similar purpose is fulfilled by folds; which occupy the mucous membrane of the alimentary canal, as well as the papillæ (Tab. IV. Fig. 62, *d e*) of the corium, the conjunctiva, the mucous membrane of the nose, the cavity of the mouth, the urinary bladder, the vagina, and many other parts.

856. The structure of the secreting glands is based upon the formation of depressions, as shown in Fig. 141. The glands of the stomach exhibited n Fig. 78 offer one of the simplest examples. The tube (*a*) in the walls of which the blood-vessels run encloses a space, which opens by one extremity into the cavity of the stomach.

857. There are two methods by which surface can be still more densely packed. The secreting cavity is produced into a long and small tube, which is rolled up as closely as possible (Tab. IV. Fig. 62, *o p*); or it branches continually like a tree, into an increasing number of subordinate excretory ducts, which are compressed together in the same manner (Tab. IV. Fig. 53, *b c*). The tubular glands are an example of the first case; and the ramified, of the second.

Fig. 143 is a diagram of a cutaneous gland, such as is called a spiral or sweat gland. The common duct first divides into two subordinate tubes, which are then variously coiled upon themselves. Fig. 144 represents a portion of the parotid. Here the branching continues, until

FIG. 143.

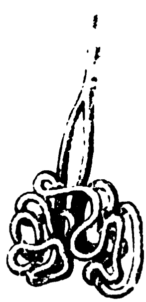
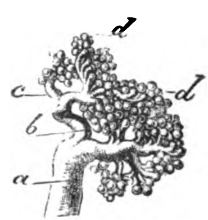


FIG. 144.



there are none but fine secreting tubules, which are visible under a low magnifying power. These terminate by rounded blind dilatations, or vesicles. (Tab. IV. Fig. 52, *b*.)

858. It is obvious that nature is not exclusively bound to any of the types just described. We find, in fact, that the same organ of secretion sometimes enlarges its surface in different ways. The tubes of the cutaneous glands (Tab. IV. Fig. 52, *n* and Fig. 143), and those of the kidney, (Tab. V. Fig. 55 and Fig. 153) bifurcate a few times before they attain a great length, and become coiled up. The terminal vesicles of the ramified glands generally exhibit a smooth internal surface. But

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we have already seen (§ 725) that the pulmonary vesicles possess folds, which additionally increase the respiratory surface.

859. We have no means of accurately determining the extent of secreting surface contained in the glands. But estimates which are rather too small than too large teach us, that amounts are often attained in this way, such as seem incredible at first sight. The secreting surface of one parotid gland may be set down as about two-thirds that of the skin. A testicle presents about $2\frac{1}{4}$ square feet, a kidney about $48\frac{1}{2}$, and a lung at least $64\frac{1}{2}$.

860. The quantity, velocity, and quality, of the blood that circulates in a secreting organ, must exercise an important influence upon the exsudation itself. The kidneys, which are intended for the rapid removal of superfluous water, are therefore supplied by the wide renal arteries. The large circumference of the pulmonary artery (*a*, Fig. 87, p. 174) has also the object of allowing as much blood as possible to be carried to the lungs in a short time. Other circumstances being equal, a gland provided with more numerous capillary vessels may furnish a very different secretion, since the dilatation of the channel (§ 689) diminishes velocity (§ 106) and permits a different process for equalizing diffusion. If the channels of the blood are so arranged that pressure is raised or depressed, we get a second important influence. We shall hereafter find that phenomena of this kind are best seen in the kidneys and the liver. The instance of the bile plainly shows what an influence is exerted by the admixture of the blood upon the quality of the secretion: since the liver which prepares it offers a marked exception to the other glands, in being supplied with blood from the portal vein, instead of from the arterial system.

861. The coats of the vessels, the limitary membrane, and the endothelium, of the glandular ducts, form a partition, the molecular constitution of which probably plays an important part in all excretory processes. Hitherto this subject has not received a very careful physical investigation. But one may foresee that the truth will only be brought to light by very round-about ways. For the tunics of the finest excretory canals are too minute to be subjected to special experiments on their diffusive capacity. Their physical characters are often essentially altered shortly after death. It is for the most part impossible to imitate in fragments of the dead body, those collateral conditions of pressure, current, and proper egress, which exist during life. And finally, it is evident that the operations producible by independent contraction cannot possibly be repeated in the dead parts.

862. Recent microscopic researches strongly indicate that many secretions are the result of still more complicated phenomena. The interior of the stomach-tube of the pig (which is represented highly magnified by Fig. 145), is covered by cylindrical epithelia apposed to

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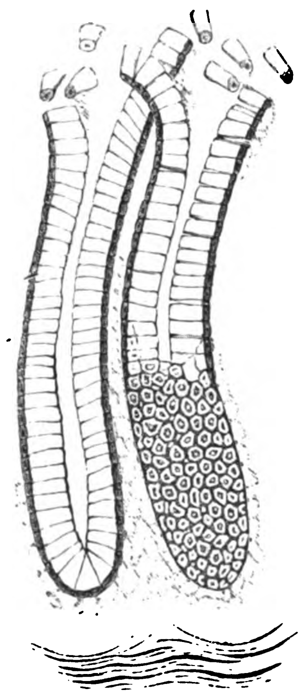
each other like a palisade. And the gastric juice which they secrete is not a mere chemical solution, but a mixture of a mucous fluid with granules, nuclei, and cells. We shall hereafter see that something similar to this is the case with all kinds of mucus. A homogeneous fluid which exsudes from the blood-vessels dissolves certain constituents of the epithelia that are simultaneously produced; while others are mechanically mixed with it, to form a solid residuum. Hence the resulting secretion contains three constituents, a fluid which is rapidly secreted, the dissolved products of an endothelium which is more slowly produced, and insoluble relics of these or other structures.

FIG. 145.



863. A microscopic examination of the liver, kidneys, and testicles, also leads to the conviction that many of the compounds found in the secretions formerly occupied the interior of gland-cells. The human liver contains a great number of peculiar cells, some forms of which are shown in Fig. 146, as they appear under a magnifying power of 255 diameters. These often contain yellow globules, or yellowish masses, of indefinite outline, possessing the chemical qualities of certain constituents of the bile. The cells in the kidney-tubes of many invertebrata (compare Tab. V. Fig. 45, *a*) contain granules of uric acid. The moving seminal elements—wrongly called spermatic animalcules—(Tab. V. Fig. 76) are begun in parent-cells, which gradually break up and disappear. Here Nature works by a continuous slow growth during the period of rest. So that materials, which require a long time for their development, can be thrown off at any time with great rapidity. From these and similar facts many observers conclude, that the formation of parent-cells is an important sign of secretory activity.

FIG. 146.

864. The question has frequently been raised, whether the action of the glands is based upon mere phenomena of filtration and diffusion, or upon more recondite organic processes. This inquiry may to a great extent be answered by what we have already seen. The original fluid mixture comes from the blood and the nutritional fluid. The result will therefore be greatly determined by the surplus pressure of these juices, and by the character of the partitions (§ 861). These are simple physical actions,

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the effects of which must vary with the structure and circumstances of the secretory organs. This may perhaps explain why many serous secretions contain large quantities of salts (§ 143); why the urea previously formed in the blood passes off almost exclusively by the urine without any decomposition; and why the yellow colour of this fluid, and of the bile, is wanting in the saliva and the different kinds of mucus. On the other hand, the facts mentioned in § 863 show that many secretions require the organic development of cells. If there is not time for this process, the secreted fluid has a watery and more or less abnormal constitution.

865. We shall hereafter find that some serous or mucous fluids are given off at various parts of the body. But others can only be prepared by special glands. The sperm is only produced in the testicles. And since the human spermatic artery is distinguished from all others by its great length and small width, one might imagine that the peculiarities of circulation thus produced essentially aided the development of the secretion. But, in most animals, this arrangement is absent. And Berthold's experiments show that, in birds, the proper vascular and nervous connection is not essential. For, after allowing the excised testicle of a cock to become attached to the intestine, he found that it still contained spermatic elements. Hence the structure of the spermatic tubes, and their previous contents, together suffice to this continuance of development.

866. It is obvious that the fluid contained in the tubes of a gland offers a certain obstacle to subsequent secretion. But, in most instances, the open ducts prevent the accession of a counter-pressure sufficient to check all further exudation. Now, since towards the blind extremities of the ramified glands their surface increases, and the sum of the calibres of the subordinate tubes is greater than that of their trunk, the continuous process of secretion furnishes a *vis à tergo* (§ 545), which propels their fluid contents with an increasing velocity (§ 106). But as this alone would rarely offer a sufficiently certain or rapid means of propulsion, nature aids it by others.

867. The excretory ducts of the larger glands, such as the ureters (*u*, Fig. 119, p. 208) or seminal ducts, are capable of vermicular movements as rapid and vigorous as those of the intestine (§ 399). Under the microscope, unstriped muscular fibres (Tab. IV. Fig. 59) may be seen in their middle coat. It is true that the smaller ducts of glands generally exhibit an uniform middle tunic (Tab. V. Figs. 64, *a*, 65, *b*). Still we shall find that this does not disprove their contractile power.

868. The contraction of neighbouring muscles sometimes extrudes the contents of excretory organs. It is probable that the muscles of mastication act thus upon the parotid gland. But nature does not trust

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exclusively to such assistance. All these glands can give out large quantities of fluid, even when the neighbouring muscles are at rest.

869. *The Secretion of the Skin.*—The comparative extent of the cutaneous surface varies greatly at different periods of life. We have already seen that (§ 89) the skin of an adult man forms a surface of about 2325 to 2550 square inches. Hence one pound of the body corresponds to about 20 square inches, and a cubic inch of its volume to from ·58 to ·74 square inches. While a new-born female infant, with a weight of 3lbs. 14½ ounces, and a bulk of 105·76 cubic inches, presented a cutaneous surface of 185 square inches. So that a pound of its weight, and a cubic inch of its volume, had a surface of 47·44 and 1·75 square inches respectively. This difference does not exclusively depend upon the greater development of the adult skeleton; but appears rather connected with the fact, that small bodies have proportionably larger surfaces.*

870. We have already (§ 839) learnt the chief condition under which sweat is poured out. Since the skin warms the surrounding atmosphere, watery vapour is constantly passing off, even when the air is saturated with vapour at its own temperature (§ 191). In sweating, the organism sets free larger quantities of fluid. In general, the act is due, either to a greater distension of the skin with blood, or to an alteration in its porosity, or to an union of both these causes.†

871. Many have supposed the sweat to be formed by the glands represented in Fig. 143, p. 264, (Tab. IV. Fig. 42, *i* to *p*), and which, from the twisting of their excretory ducts, have been named spiral glands. Indeed they are often expressly called the sweat-glands. It is certainly probable that a liquid secretion would exsude from the free openings of these gland-tubes (Tab. IV. Fig. 42, *i*) more easily than it would penetrate the dense cutaneous tissues themselves. But since sweat is often poured out in places where few or none of these tubes are present, the skin itself must form its means of egress.

872. The sweat is one of the most dilute fluids of the body (§ 34). Its solid residue forms but ½ to 1 per cent. It contains chloride of sodium and ammonium, and phosphate of lime, with other salts, and organic matters. It also contains epithelial scales (Tab. II. Fig. 32) and fatty substances; which are due to the admixture of the sebaceous secretion of the skin. The remarkably sour smell of many kinds of sweat appears to depend, partly on acetic acid, partly on volatile fatty acids (§ 848).

* It may be useful to illustrate this well known fact by an example. A sphere having a radius of 1 inch would possess a surface and capacity of 12·6 square, and 4·2 cubic, inches respectively; which would be increased to 50·4 and 33·6 in one having a radius of 2 inches. So that each inch of volume would correspond to 1½ of surface in the larger, and 3 in the smaller, body.—EDITOR.

† These vaporous and liquid secretions are often distinguished from each other as the insensible and sensible perspiration.—EDITOR.

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873. When sweat ceases to be produced, the water and other volatile compounds which have collected on the surface of the body gradually evaporate. Other substances are precipitated in the solid form; so that microscopic crystals of chloride of sodium (Tab. I. Fig. 1) or other salts are sometimes found on and between loosened scales of the cuticle (Tab. IV. Fig. 62, *i*, *c*, *a*).

874. Violent perspiration gets rid of so much water that the necessity of compensation is evinced by thirst; and the quantity of urine is visibly diminished. Many morbid phenomena indicate that the conditions under which sweat is poured out are not yet accurately known. Persons suffering from subcutaneous dropsy usually exhibit a dry skin. Sweat concludes many febrile attacks. Copious perspiration often accompanies fatal degenerations of the infantile brain. The vascularity and temperature of the skin do not always vary in proportion to these alterations. The cold sweat which accompanies vomiting or syncope is an instance of this fact. In these cases we are justified in supposing that the porosity of the organic partition, which depends upon the nervous system, plays an important part.

875. Many portions of the skin possess special glands which, from the fatty matter they secrete, are called sebaceous. Those which secrete the wax of the ear are constructed after the type of the tubular glands (figured in Fig. 143, p. 264). The Meibomian glands of the eyelids form tubes, the whole length of which is studded with lateral vesicles (Tab. IV. Fig. 52). On the other hand, the numerous small glands which accompany the hairs (Tab. IV. Fig. 63, *h i k*) ramify like a tree, and terminate by globular heads. They pour their fatty contents into the cavity out of which the hair passes (Tab. IV. Fig. 63, *g*): while other larger glands, such as those which occur in the neighbourhood of the alæ nasi, in other parts of the face, and in the labia pudendi, open immediately upon the surface of the skin.

876. The sebaceous glands of the hair furnish a fatty mixture which anoints its shaft, (Tab. II. Fig. 39, Tab. IV. Fig. 63, *c d*) making it smoother and more pliant. It thus forms a kind of pomatum, provided by nature itself. Its superfluous part, together with the fatty secretion of other sebaceous glands, becomes mixed with the desquamated scales of the cuticle (Tab. II. Fig. 32). This mixture, the fat of which is easily altered by the atmosphere, forms the sebaceous secretion of the skin, and the wax of the auditory duct. The fatty substance on the corona of the glans penis is produced by the simple sebaceous glands of this part.

877. *Serous secretions.* To this class belong the fluids contained in the shut serous sacs of the cerebral and spinal membranes, the pericardium, the pleura, and the vaginal tunic of the testicle. We have already (§ 850) learnt the cause which normally limits their quantity: in many morbid states they are greatly increased; so as to give rise to a dropsy of the particular sac affected.

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878. The fluids under consideration generally form limpid, colourless, or at most faintly yellowish, solutions. It is questionable whether the epithelial scales they sometimes contain are not the results of a desquamation which occurs after death. Most of them have 1 to 2 per cent of solid residuum, which generally contains albumen and other organic matters, with what is often a very large proportion of ashy constituents. Their mechanical use has (§ 94) already been explained.

879. The aqueous humour of the eye closely resembles the serous secretions. It also contains less than 2 per cent of solid matters; in which the chloride of sodium amounts to nearly half as much again as the organic compounds. In the fluid which moistens the vitreous substance the above proportion of this salt is increased. And Millon found that both these fluids contain urea.

880. *Mucus.*—It has already been remarked (§ 862) that mucus is not a simple secretion. A dilute and richly saline exsudation dissolves those epithelial cells which are not too horny; and thus acquires a mucous character. Hence we find it mechanically mixed with fine granules; with the nuclear structures called mucous corpuscles (Tab. II. Fig. 31, *d*); and often, with perfect or half-corroded cells. The contactive effects of many kinds of mucus probably depend upon these variable constituents (§ 418). These facts also explain why, when the secretion of the nose is hurried by the contact of cold air or by catarrh, a thin saline mixture is poured out.

881. For the same reasons, the quality of mucus is liable to great variation. The ordinary mucus of the nose contains from 88 to 94 per cent of water, and that of the pulmonary membrane about 95; while the gastric juice, which is secreted more copiously, has 98 to 99 per cent. The compounds afterwards added by solution generally cause the organic to predominate over the ashy constituents.

882. Mucus is produced in two ways: in special glands, or on free surfaces. The former may either simply increase the secreting surface, or may assist to prepare special juices, which are subsequently mixed with the rest of the mucus. To the latter class probably belong the cylindrical follicles of Lieberkuehn; which crowd the mucous membrane of the small intestines, and which are represented by the accompanying diagram (Fig. 147). They form a mass below, while the intestinal villi project above: so that both the types of increase of surface exhibited in our diagram (Fig. 141, p. 263) are here present together. The glands of Brunn,—which occupy the duodenum, and terminate by dilatations like grapes upon a stalk,—probably furnish a mixture different from the neighbouring intestinal mucus. Their outline is represented by Fig. 148.

883. As yet we know very little about the import of those shut capsules, which are irregularly met with in many mucous membranes. They are scattered over various parts of the stomach and intestine; where they

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are called lenticular, solitary, and aggregated glands. To these also belong the *glandulæ Nabothi* of the mucous membrane of the uterus. The Peyerian patches are aggregations of vesicles, such as are represented by the globular enlargements in Fig. 142. Cylindrical follicles of Lieberkuehn are also found around them. And, according to Bruecke, the absorbents of the intestine may be injected from their interior.

FIG. 147.

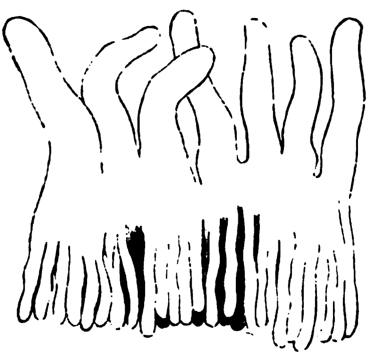
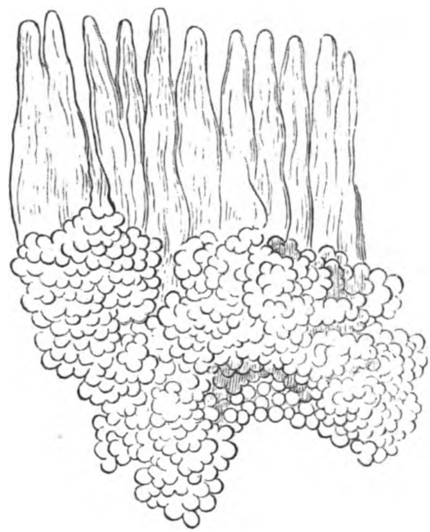


FIG. 148.



884. Each of these closed vesicles contains a mucous and usually alkaline fluid; in which we again find a mechanical admixture of cells, nuclei, and granules. Since in many dead bodies they are very numerous, while in others they are very few, it may be conjectured that their number depends upon secondary causes, of which we are as yet almost ignorant. But it is probable that their disappearance is due to their contents being either absorbed during life, or poured out from a rupture which occurs after death.

885. The different kinds of mucus are useful either by their mechanical or chemical properties. We have already (§ 80) seen that they greatly reduce the obstacle which friction offers. Many of them have the power of uniting bubbles of air into a kind of emulsion (§ 493), so as to present a frothy appearance. Others, such as the intestinal mucus, contribute to the minute division of the fats and the residue of the food (§ 365). All of them protect the surfaces they clothe from the injurious effect of the fluids with which they are in contact; such as the atmospheric air, the bile, the urine, or the menstrual blood. Finally, the chemical qualities of some particular kinds of mucus endow them with contactive powers.

886. The characters of the *synovia*,—which is furnished by the synovial

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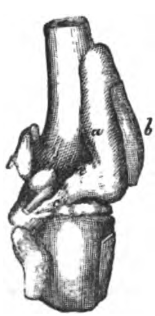
membranes, and collects in the articular cavities of the joints—place it, as it were, midway between the serous and mucous secretions. It forms an alkaline, colourless, or faintly yellowish mixture; the tenacity of which, according to Frerichs, [30]) depends upon mucus. Here again the mucous character is produced by the solution of epithelia: and, according to this observer, it increases with the frequency of movement. In the latter case the density of the synovia therefore increases. That of the knee-joint of a stall-fed ox contained 97 per cent of water; while that of an animal which had spent the whole summer at pasture had but 95 per cent. Mucus, albumen, and other organic matters as yet but imperfectly known—together with fat, chloride of sodium, sulphates and phosphates of the alkalis, carbonate of lime, and earthy phosphates—are found in the fresh fluid, and in the ashes of its solid residuum. Microscopic research teaches that the mechanical admixture consists of fragments of epithelium. At any rate this is the case with synovia obtained after death. The fat globules sometimes remarked seem to be only aggregated by violence.

887. The fluid is prepared by the synovial membranes themselves, and not by any special glandular structures imbedded in them. The Haversian glands of the knee-joint are mere cushions of fat. But, in this joint, certain free portions of the synovial membrane are clothed with villi, which increase the secreting surface.

888. The synovial membranes of many joints, (such as those of the shoulder, the knee, and often the hip), are prolonged into supplementary sacs called *bursæ mucosæ*. According to Weber, when the knee-joint is filled by a congealed mass, it has the shape represented in Fig. 149. A mucous bursa, *a*, passes under the common tendon, *b*, of the *extensor femoris;* and a second and third (*c* and *d*) run with those of the hamstring muscles. Thus, according to the difference of position, the viscid synovia which diminishes friction (§ 80) can either pass into these supplementary sacs, or can retreat into the cavity of the joint.

FIG. 149.



889. The closed *bursæ mucosæ*, and the sheaths (§ 850) frequently found under the muscles and tendons, contain a fluid similar to synovia. Hitherto, however, its properties have not been further examined. But it is probable that it also is a serous fluid, which only becomes viscid subsequently.

890. *The lachrymal secretion.*—The opposite wood-cut (Fig. 150) represents the left human eye. The lachrymal gland (*a*), consisting of an upper and lower division, occupies the upper, outer, and anterior part of the orbit. It belongs to that class of secreting organs which ramify,

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and end by vesicular dilatations (Fig. 144, p. 264). Delicate excretory ducts convey its fluid to the outer angle of the eye. Here it reaches the sac of the conjunctiva, the small space which lies between the surface of the eye (*b*, *c*, *d*) and the eyelids (*e* and *f*). From hence it is conducted onwards by a twofold process. It advances in the fissure of the conjunctiva, just as water rapidly spreads between two moistened glass plates in close apposition to each other. Besides this, it mixes with the fluid previously present.

891. Several other secretory organs in this situation furnish mixtures of different kinds, which are united with the product of the lachrymal glands. The conjunctiva itself—which clothes the surface of the cornea (*b*, Fig. 150), the sclerotic (*d*), and the interior of the eyelids,—adds a fluid; which is chiefly secreted by its more vascular parts, and by the few mucous glands it contains. The Meibomian glands imbedded in the eyelids (Tab. IV. Fig. 152) prepare a fatty secretion, which is poured out at their margins. The glandular *caruncula lachrymalis* at the inner angle of the eye (*g*, Fig. 150), probably adds another mucous secretion.

892. Since the fluid covering the eye is exposed to the air, a variable quantity will evaporate (§ 186). A special apparatus carries the remainder into the cavity of the nose.

893. On everting the margin of either eyelid before a mirror, we observe a dark point, called the *punctum lachrymale* (*h i*, Fig. 150). It

FIG. 150.

is the aperture of a small excretory duct, the lachrymal canal. The two canals (*k* and *l*, Fig. 150), open into the lachrymal sac (*m*), which passes off into the lachrymal duct (*n*). This finally opens into the nasal fossa, below the anterior part of the inferior turbinated bone.

894. The propulsion of the tears is aided by a frequent repetition of the act of winking. They thus pass into the lachrymal canals (*k l*, Fig. 150), the lachrymal sac (*m*), and the lachrymal duct (*n*), to discharge themselves into the cavity of the nose and mingle with the mucus there. The ciliated cylindrical epithelium (Tab. II. Fig. 36), which occupies the surface of the mucous membrane of the nose, is continued into the

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lachrymal duct and sac. If the current it produce be directed downwards, it will aid in the discharge of the tears.

895. Many observers have supposed that the respiratory movements also assist this propulsion. The lower outlet (*o*) of the lachrymal duct (*n*) often possesses a more or less complete fold, which is capable of acting as a valve. It permits fluids to pass unhindered from the lachrymal duct into the nasal cavity. While if air or any other substance attempts to take the reverse direction, it shuts. It is therefore imagined, that the draught which accompanies inspiration (§ 735, *et seq.*) assists the passage of the tears into the nose, while the valve prevents the entrance of air or mucus during strong expiration.

896. From what has just been stated, it is evident that a more or less continuous stream of tears runs from the outer towards the inner angle of the eye. Apart from evaporation (§ 892), the quantities received and discharged are equal. Thus the eye is only maintained moist; neither swimming in tears, nor allowing any surplus to pass out between the eyelids. And since the Meibomian glands open upon the margin of the eyelid, their fatty secretion enables the surface in this situation in some extent to resist the passage of watery fluid.

897. Sometimes the tears are secreted so copiously, that the current towards the nasal cavity becomes insufficient to carry off all the fluid. A large quantity therefore collects in the conjunctival sac, and finally emerges from the fissure of the eyelids. This unusual mode of discharge constitutes weeping, an act which has some analogy to that of sweating (§ 839).

898. Another abnormal form of discharge is seen in lachrymal fistula. When the lachrymal duct (*n o*, Fig. 150, p. 273) is obstructed, the sac (*m*) is distended by a constantly increasing quantity of fluid, a fact which proves that the act of inspiration is not the exclusive condition of its passage hither. An external fistulous opening is thus finally produced, the closure of which is prevented by the chemical irritation of the tears that constantly pass through it. If the natural outlet is restored, the supplementary opening gradually becomes less disturbed by the passage of the injurious secretion, and so heals up.

899. The quantity of tears which moistens the conjunctival sac in the ordinary state of repose, is too small to be subjected to analysis. Hence the only fluids which have been used in physico-chemical researches are those poured out during weeping; *i. e.*, during a flow of tears excited by unusual collateral causes. It might be expected that this mixture, which is prepared and poured out with unusual rapidity, would contain more water and salts, and less mucus, than under ordinary circumstances (§ 864).

According to Frerichs this dilute secretion consists of 98·7 to 99 per cent of water. It contains epithelia, and sometimes fatty substances,

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together with mechanical admixtures. Its organic matters consist partly of albuminous and mucous substances. In its ashes are found chloride of sodium, and phosphates of the alkalis and earths.

900. In morbid states, the foreign admixtures may exceed the original solid residuum. On collecting the turbid fluid which constantly flowed from a blind human eye, I found that it left 5·9 per cent of residue. It contained numerous more or less perfect epithelial scales, very small fatty molecules, crystalline structures (in all probability chiefly inorganic salts which had only been precipitated on standing), and minute molecular corpuscles, the exact nature of which could not be determined.

901. The crust not unfrequently found in the inner angle of the eye, especially in the morning, contains large quantities of more or less perfect epithelial scales, with small granules and oil-globules. Hence in many respects it resembles the wax of the ear, and the sebaceous secretion of the skin (§ 875). The globe of the eye is so arranged, that the eyelids exert a pressure, which tends to propel the substances contained in the conjunctival sac towards the inner angle of the eye. The flow of the tears is thus facilitated from its very commencement (§ 894). In this way a particle of dust which has fallen into the eye, after some time passes to its inner angle. The same fact explains why the crusts just mentioned are oftener met with at the inner angle of the eye than at the margins of the eyelids.

902. From the above statements it is easy to see why the eye remains moist, even after the destruction of the lachrymal gland, or the loss of a great part of the conjunctiva. The idea that the aqueous humour transudes the cornea to gain the conjunctiva has little support from theory; and receives none from the experiments instituted by Frerichs.

903. *The saliva.*—A series of large glands furnish the secretions called the saliva and the pancreatic fluid. Each of the two parotids forms a tolerably flat mass, which is thicker posteriorly, and lies before and beneath the ear. The duct of each opens on the inner surface of the cheek, opposite the first or second molar tooth of the upper jaw. The duct of each of the two submaxillary glands behind and beneath the lower jaw opens by an orifice near the *frænulum linguæ.* Each of the two sublingual glands has a number of efferent canals, which also open beneath the tongue. Occasionally some of these are united with others from the submaxillary glands, to form a single duct. The lingual glands are situated at the apex of the tongue. The pancreas (*p q*, Fig. 551, p. 280) empties itself into a duct which opens into the descending portion of the duodenum (*i*).

904. Taking the volume of the sublingual gland as 1, the submaxillary has a bulk of 4, the parotid from 8 to 9, and the pancreas 27 to 28. Thus the salivary glands of both sides form a total of 27 : or something less than the single pancreas.

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905. We have already seen, (§ 422) that the spittle is a mixture of pure saliva with the fluid secreted by the mucous membrane of the mouth, and by the various glands imbedded in it.

906. The activity of these organs varies greatly according to circumstances. In a state of rest, the salivary glands scarcely secrete any fluid; while, under other circumstances (§ 423), they pour out a large quantity. In such cases the amount of mucus is also increased, though to a smaller extent. Salivation, or ptyalism, is a morbid increase of the spittle.

907. Such variations render it difficult to determine how much of these secretions generally escapes in the 24 hours. And when we add that some of the fluid of the mouth is involuntarily swallowed during waking, and still more during sleeping, it will be evident that all the estimates hitherto made are necessarily inaccurate.

908. It is generally supposed that an adult man secretes about 10 to 14 ounces of spittle daily. Mitscherlich, who had the opportunity of examining a man with a fistula of the parotid duct, obtained an average of about 2·8 ounces fluid from this opening in the 24 hours. And supposing that all the salivary glands together make up a secreting surface $3\frac{1}{3}$ times as large as that of one parotid, and act simultaneously, we should get a total of 9·4 ounces. The remainder would be due to the lingual glands and the mouth.

Jacubowitsch [31]) sought for an approximative solution of this problem by tying the efferent ducts of the several salivary glands in dogs, and then determining the amount of fluids poured into the cavity of the mouth. But the numbers thus obtained are invalid. For not only were the animals placed in a morbid state by the artificial interference, but the cavity of the mouth was stimulated with vinegar, and a part of its fluids was undoubtedly lost by evaporation and deglutition. According to his researches, the quantities per hour amounted to 1·737 ounce for the two parotids, 1·37 for the two submaxillaries, and ·875 for the orbital and sublingual glands and the mucous membrane of the mouth. But since this would give 95·3 ounces for 24 hours, it is evident that the disturbances above mentioned—although to some extent corrective of each other—caused a great increase in the total quantity of fluid secreted.

909. We have already become acquainted (§ 425) with the watery and other constituents of the oral spittle. Epithelium (Tab. II. Fig. 31) and mucus usually form more than $\frac{1}{3}$ of the solid residuum. Besides this it contains ptyaline, and other still more recondite nitrogenous compounds, with traces of fat. And in addition to the ordinary salts—such as chloride of potassium and sodium, with phosphates of the alkalis and earths, and some oxide of iron—it contains sulphocyanide of potassium. This salt, which betrays itself by the red colour it produces with the

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salts of iron, amounts at most to $\frac{1}{10000}$th of the fresh fluid. So that if we suppose an adult man to secrete 9·4 ounces of mixed spittle in 24 hours, this quantity would correspond to ·42 grains of the sulphocyanide : a quantity so small, that it could not possibly produce any injurious effects.

910. In salivation (§ 906), which sometimes arises spontaneously, but is generally due to the use of metals, and especially of quicksilver, the secretion is not necessarily more watery than the ordinary fluid of the mouth. It frequently contains mucus in large quantities; and albumen, or even urea, as stated by Wright. According to Gmelin, we may sometimes establish the presence of mercury in the saliva of persons undergoing a mercurial course. The salivary calculi, which scarcely ever occur save in the ducts of the sublingual glands, are composed of carbonate and phosphate of lime, to the extent of more than $\frac{3}{4}$ths of their substance. The remainder consists of an organic basis, with small quantities of alkaline salts.

911. Just as a large quantity of saliva is poured into the mouth during the act of eating, so the attempt to collect the pancreatic fluid of living animals only succeeds at the period of intestinal digestion. We have already (§ 461) seen, that the composition of this secretion varies greatly according to the circumstances under which it is obtained; and that it is also very much inclined to decomposition, a peculiarity to which its digestive action is probably chiefly due.

912. Dogs undergo extirpation of the pancreas without injury. And since men may live for years with complete degeneration of this secreting organ (*p q*, Fig. 151, p. 280), we are justified in supposing that its function is not essential to the maintenance of life. Such persons sometimes vomit large quantities of watery fluid; and this has been regarded as pancreatic juice which has undergone regurgitation into the stomach. Since irritation of the salivary glands of the mouth often causes the secretion of large quantities of fluid, a similar process may perhaps occur with the pancreas. But it is more probable that these fluids do not come from this gland, but consist of saliva, which has been secreted in answer to gastric irritation (§ 423), and afterwards swallowed.

913. *The Bile.*—The liver is distinguished, not merely by volume and density, but also by its peculiar relations to the vascular system. We have seen (§ 681) that the veins of the stomach, intestine, pancreas, and spleen, unite in the portal vein. This ramifies in the interior of the liver, receives the veins of the gall-bladder and hepatic ducts, unites with the finest branches of the small hepatic artery, and finally ends in the capillaries which are continuous with the roots of the hepatic vein.

914. If the hepatic artery, the portal vein, and the hepatic veins, be injected to their finest branches with substances of different colours, an

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examination of suitable sections under the microscope will show that the liver consists of a number of roundish grains or lobules, more or less distinct from each other. In the intervals of these run the branches of the hepatic artery and portal vein. A number of capillaries, united with each other so as to form a network, pass into the substance of the lobule, and converge towards its centre. A common trunk which descends in the middle of the lobule, forms one of the numerous rootlets of the hepatic vein, the terminal trunk of which opens into the inferior vena cava (*l*, Fig. 119, p. 208). Hence the network of capillaries, from which the secretion chiefly proceeds, contains a dark-red portal blood. While the capillaries of other glands receive a bright-red blood from their arteries.

915. The precise mode in which the hepatic ducts terminate is as yet undecided. If the hepatic canals be injected from the duct with some congealing substance, they may be seen to bifurcate; and subsequently they unite with each other by occasional cross-branches. In some of the lobules we may remark a network of the coloured substance, having meshes which appear to be either empty, or are penetrated by extremely fine capillaries. But, on the other hand, the fresh liver chiefly exhibits regular aggregations of the liver cells (Fig. 146, p. 266), sometimes separated by clear radiating intervals. Many observers suppose these cells to occupy the interior of a structureless membrane which is continued from the middle tunic of the biliary canals. But from injected preparations, Gerlach[32]) concludes that these canals, after surrounding the lobules of the liver with a network, and sending nets into their interior, are continued into mere dilated spaces, which are devoid of walls and occupy the intervals of the hepatic cells. A third view makes them terminate in flattened blind sacculi lying close to each other.

916. The obscurity which attaches to the minute anatomy of the liver is again met with in most of its physiological relations. The liver of the adult weighs from 2·2 to 3·75 pounds. Assuming its average to be 46·3 ounces, and that of the parotid ·7 ounce, the former would be 66 times as great. And if the quantities secreted by these glands were proportionate to their weight, the liver would furnish about 11 pounds of bile daily. But it is very improbable that so much is really secreted. And since the tissue of the parotid is looser, and its ducts larger, than those of the liver, a cubic inch of the latter would contain more secreting surface. Hence it is probable that the bile is secreted much more slowly than the saliva.

917. It has often been attempted to solve this question by means of experiments on animals. Nasse and Platner found that a dog weighing from 19 to 21 pounds gave off from 5 to 6 ounces of bile daily through a biliary fistula. Stackmann[33]) tied the common hepatic duct (*n r*, Fig. 151) in living cats, and placing a canula in the evacuated gall-

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bladder (*l*), collected the bile which flowed out in definite periods of time. Reducing these safer results to a pound of bodily weight gave as follows—

Accompanying Circumstances.	Quantity of Bile, in grains, for each pound of bodily weight. The hours referred to are those which followed the commencement of the experiment.		
	First Hour.	Second Hour.	Third Hour.
From 2½ to 3 hours after feeding	3·92 to 6·51	2·59 to 5·11	1·54 to 5·04
From 12 to 15 hours after feeding	5·74 „ 9·1	5·39 „ 6·23	4·55 „ 5·88
Twenty-four hours after feeding	2·52 „ 4·34	1·82 „ 3·92	1·12 „ 3·99
Fasting from 48 to 240 hours	1·54 „ 4·48	·63 „ 2·52	·35 „ 2·24

From this we see that cats pour out the largest quantities of bile from 12 to 15 hours after feeding. If they are made to fast for some days, the secretion gradually diminishes. Hence it is not merely due to that metamorphosis of the blood which is produced by the various functions, but is evidently in part the result of the elaboration of the food.

918. Assuming an average of 4·2 grains per hour and pound, for cats fed as usual, we shall get 100·8 grains for the twenty-four hours. According to this, the daily quantity of bile would be about $\frac{1}{70}$th the weight of the whole body.

919. In the cat, the proportionate weight of the liver is liable to great variations. For instance, it may form $\frac{1}{11}$th or $\frac{1}{45}$th of the entire body. Usually, however, it ranges from $\frac{1}{29}$th to $\frac{1}{32}$nd. In the adult man, the healthy liver generally constitutes from $\frac{1}{33}$rd to $\frac{1}{42}$nd of the weight; a fraction which is rather a small one. Disregarding this, as well as the scarcely comparable circumstances of secreting surface and vascularity, and taking $\frac{1}{70}$th as a basis for calculation, a man weighing 132·38 pounds would secrete an average of 30¼ ounces of bile in the twenty-four hours. And supposing the average weight of the human liver to be 46⅓ ounces, its specific gravity 1·07, and hence its volume 74·7 cubic inches, each cubic inch of its substance would furnish only 177· grains of bile daily. While, since a cubic inch of parotid probably furnishes 1013 grains of saliva, the liver must work from 5 to 6 times as slowly.

920. The trunk and branches of the portal vein have a comparatively large diameter. If we add to these the ramifications of the hepatic artery, the extremely numerous and dense capillaries, together with the large efferent hepatic veins, it will be obvious that the gland receives a large quantity of blood. But, in spite of this, the amount of its secretion is but small. Hence we might expect that the difference between the afferent portal, and the efferent hepatic, venous blood would be so very slight, as to elude our present means of analysis, and be, to a great extent, concealed by collateral circumstances.

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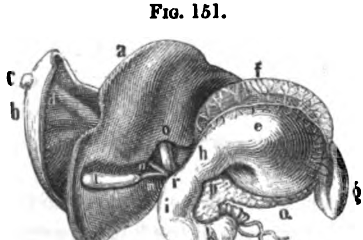
921. According to Schultz, Simon, and Schmid, the water of the portal blood varies greatly in quantity: so that it is sometimes more, sometimes less, dense than the blood of the carotid artery, the jugular, or the hepatic veins. For instance, its solid residue ranges from 18 to 28 per cent. Fasting horses and dogs have a watery portal blood, while that of the well-fed animals contains more solid matters. Sometimes it contains more fat, colouring matter, and salts, but less fibrine, than other kinds of blood. A comparison of the numbers on which these statements are based shows that their differences are much too great to depend only on a slow secretion of the bile. On the contrary, they may rather be ascribed to unavoidable errors of analysis, together with the influence exerted by the absorption of foods and drinks, and other circumstances.

922. Such an explanation may also illustrate the great difficulty of deciding, whether the most essential constituents of the bile are previously formed in the blood. We shall see that the kidneys secrete much more rapidly than the liver. But, in spite of this, the most essential element of the urine—viz. its urea—exists in the blood in such very small quantity, that its presence can only be established with extreme care. Now, since the daily quantity of bile is probably not greater than the quantity of urine secreted in the 24 hours, while more blood seems to pass through the liver than through both kidneys, we can only expect such traces as may long elude chemical analysis. This remark especially holds good for the chief biliary substances which will shortly be mentioned. It is true that certain of its collateral ingredients,—such as its cholesterine and colouring matter—may be verified in the blood. But they are also met with in other fluids.

923. The bile which descends from the hepatic canals may either immediately enter the common biliary duct (*r*, Fig. 151) from the hepatic duct (*n*); or may be collected in the gall-bladder (*l*) after passing through the cystic duct (*m*). The unstriped muscular fibres of the gall-bladder, which are less marked in man than in many mammalia—such as the ox—afterwards impel the collected bile into the cystic duct (*m*), the common biliary duct (*r*), and the duodenum (*i k*). The numerous folds which occupy the cystic duct probably render this movement a slow one.

FIG. 151.



924. The bile contained in the hepatic duct (*n*, Fig. 172) already possesses a certain amount of viscidity. As yet, however, we are ignorant whether this quality is present in the finer biliary canals, or whether it depends upon the secretion of those small tubes which are contained in

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the walls of the larger ducts, and to which Theile has drawn attention. In the gall-bladder, its density and viscidity increase. It is possible that chemical metamorphoses are at the same time induced.

925. We have already (§ 467) learnt the difficulties which oppose a chemical analysis of the bile. Berzelius and Mulder suppose that a neutral organic substance, bilin, forms the most important constituent: while, on the other hand, Liebig and his school think that certain organic acids are united with soda to form fatty salts. According to the latter view, the bile resembles a soap. The Iatrochemists of the seventeenth century sought to establish a similar theory.

926. The question whether this soap is a compound of one or many biliary acids, has likewise been differently answered. According to the recent researches of Strecker, the bile contains a mixture of two soda-compounds; one of which is formed by the cholic, and the other by the choleic, acid. The cholic acid contains 67·1 per cent of carbon, 9·3 of hydrogen, 3·0 of nitrogen, and 20·6 of oxygen. Its equivalent (§ 279) is $C_{52}H_{43}N_1O_{12}$. By boiling with alkalis, it is converted into cholalic acid ($C_4H_3N_1O_2$); which, united with two atoms of water, gives glycin or sugar of glue (§ 319). The choleic acid—the hypothetical formula of which is $C_{52}H_{45}N_1O_{14}S_2$—is decomposed by putrefaction into ammonia, taurin (§ 320), and a resinous mass. Its sulphur is probably due to the taurin, which Redtenbacher regards as an acid sulphite of aldehyd-ammonia. The dyslysin, which is precipitated in the course of the alimentary canal, (§ 472) may be obtained from cholic acid by continued boiling in dilute hydrochloric acid.

927. Solid deposits of gall-stones frequently occur in the biliary ducts, and especially in the gall-bladder, which sometimes contains hundreds or thousands of such concretions. In very rare cases they consist of carbonate and phosphate of lime. Usually they are composed of cholesterine, colouring matter, margarine, and margarates. When these softer gall-stones lie closely compressed in the gall-bladder, they often acquire smooth surfaces, being polished by mutual friction. But, in many instances these cholesterine gall-stones form complete aggregations of crystals. A concretion of this kind is shown in Tab. I. Fig. 16, slightly magnified. Many of the bezoar-stones, which are regarded as the gall-stones of the antelope, consist of lithofellic acid or of bezoaric acid; while others are composed of phosphate of lime, and ammoniaco-phosphate of magnesia.

928. We have already (§ 467, *et seq.*) been made acquainted with what is at present known concerning the relations of the bile to the digestive function. Since certain insoluble products of its decomposition are given off with the fæces, it is, at least, in part an excretion. It has long been supposed that the formation of bile was necessary to the purification of the blood. Some have thought that the older blood-corpuscles are dis-

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solved in the liver of the adult, where they are either wholly or partially applied to the formation of bile. But this view is unsupported by any trustworthy proofs. Dogs in whom biliary fistulæ have been established may live for months, but they finally perish with appearances of inanition (§ 361). And though the loss of hepatic function destroys life, still this injurious effect only comes on gradually. So that the real import of the secretion of bile, or of its natural flow into the intestine, can only be deduced from the gradual synthesis of many different operations.

929. According to Bernard, the blood and liver of mammals, birds, and reptiles, contain a considerable quantity of grape-sugar. This is produced in the gland itself, independently of all amylaceous food (§ 304); but its formation ceases on cutting through the vagus nerve.

930. *The Urine.*—The secretion of urine by the kidneys fulfils two chief objects. It withdraws from the blood superfluous water, and soluble ashy constituents. At the same time, it carries off certain azotized substances which cannot otherwise be got rid of. The water of the urine, as it were, rinses the body on leaving it; so that it frees the organism from a series of compounds which have either been introduced with the food, or have been rendered unfit for use by the action of the various organs.

931. Although many of the substances given off in the urine are probably products of muscular movement, still this does not immediately necessitate its evacuation. The same remark applies to the use of nitrogenized food, which gives rise to similar results. But if, on the other hand, we introduce into the stomach considerable quantities of water, food, or drink, the urinary bladder soon becomes distended. Hence water is rapidly carried off by the kidneys.

932. From this fact it is obvious, that the function of the urinary organs must vary greatly with the accompanying circumstances. If the blood have taken up much water, an unusual quantity will exsude. This circumstance and the varying activity of the skin (§ 835) even affect the total quantity per day. Thus the same person may give off less than two pounds of urine in one day, and more than four the next.

933. Disregarding such variations, an adult of average size may be stated to secrete from 2 to 3 pounds of urine in the 24 hours. The quantity of fluid thus set free is somewhat less than that originally secreted by the kidneys, since the urine becomes slightly condensed by a long continuance in the bladder. But this circumstance does not essentially affect the limits above mentioned. Supposing the average volume of both kidneys to be 17 cubic inches, every cubic inch would daily furnish about 1000 grains, or about 2·3 ounces: an activity which would be somewhat greater that that of the parotid (§ 919), and much greater than that of the liver.

934. On making a longitudinal median section of the human kidney,

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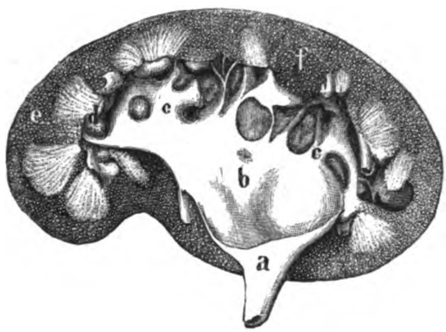
we find that the cortical substance (*f*, Fig. 152) exhibits a dark brownish-red colour, while the medullary substance (*e*) is of a clearer and whiter hue. Both of these contain urinary tubules, which are the ducts of the glands. In the medullary substance these take a comparatively straight course; while in the cortex they are very tortuous. The straight tubules open on the free surface of some peculiar projections, the mamillæ (*d*, Fig. 152). The cavities between these prominences are partially covered

FIG. 152.



with a white membrane, and are called the calyces (*c*, Fig. 152); they open into a common receiver, the pelvis of the kidney (*b*), which is prolonged into the ureter (*a*). Finally, the latter tube opens into the bladder, in which the urine collects before leaving the body.

935. A large artery, the renal, which leaves the aorta at nearly a right angle, ramifies in the interior of the kidney. Its branches, after attaining a certain fineness, form peculiar coils—the Malpighian tufts (Tab. V. Fig. 66, *a*). The arterial twigs which emerge from these are continued into a network of capillaries that surrounds the tortuous urinary tubule. The veins of the kidney unite to form a large trunk, which empties itself into the inferior cava.

A section of the renal substance under a moderate magnifying power is shown by Fig. 153. At *a* are the Malpighian coils just mentioned, *b* shows the fine arterial twigs from which they arise, *c* the tortuous, and *d* the straight, urinary tubules; the latter are seen to bifurcate here and there.

936. A special capsule (Tab. V. Fig. 66, *b c d*) surrounds each tuft to form the Malpighian body. This capsule is the dilated end of an urinary tubule (Tab. V. Fig. 66, *e*). Fine cilia (Tab. II. Fig. 36) frequently maintain a vigorous current over a greater or less extent of the internal surface of the capsule. Sometimes, however, they cannot be recognized at all; and in many cases they are only seen where the capsule becomes continuous with the neighbouring urinary tubule.

937. The use of this peculiar arrangement cannot be exactly deter-

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mined. Since curves increase resistance (§ 103), the blood will pass more slowly through these tufts, and will exert a stronger pressure on the walls of the vessels. They would thus allow the exudation of a dense solution containing peculiar substances; and would transmit a comparatively watery blood to the plexus of capillaries around the urinary tubules. But this hypothesis does not clearly explain why the water of the blood together with its soluble matters,—such as the peculiar compounds of urea, uric, and hippuric acid (§ 321)—chiefly pass off by the urine.

FIG. 153.

938. The urine, which is prepared in the tortuous urinary tubules (*c*, Fig. 153) passes from these into the straight ones, *d*. It escapes from the latter through their orifices on the mamillary processes (*d*, Fig. 152, p. 283). The fluid then gains the calyces (*c*) and pelvis (*b*) of the kidney, and finally enters the bladder (*m*, Fig. 154) through the ureter, (*k l*). All these parts possess unstriped muscular fibres (Tab. IV. Fig. 59), the contraction of which propels the urine onwards. Artificial irritation of the ureter (*k l*, Fig. 154) or its nerves in recently killed animals, often produces vermicular movements, which are directed from the kidneys (*c d*), towards the urinary bladder (*m*). This collects the urine drop by drop, and gradually becomes distended in proportion as its contents increase.

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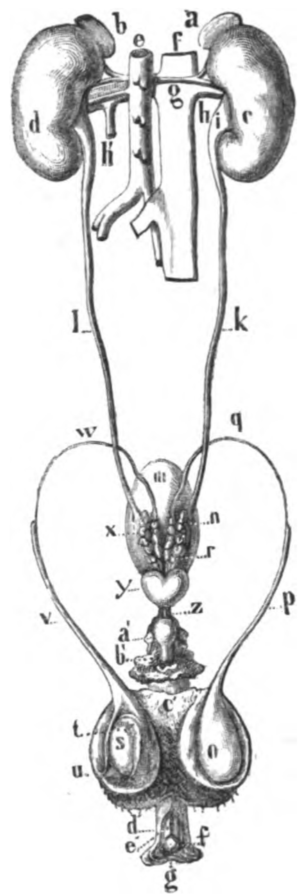
939. Occasionally a rare malformation, the prolapsus of the bladder, affords an opportunity for verifying this exit of the urine by drops from the ureter. In this malformation, the symphysis of the pubis (below *k* Fig. 27, p. 230) and the anterior wall of the bladder are wanting: while the posterior part of the cavity is exposed as a reddish irregular mass, covered with mucus. In such cases, the orifices of the ureters are seen opening from time to time to allow the passage of a drop of urine; the right ureter often acting at different times from the left.

FIG. 154.



940. A hæmadynamometer, which was introduced by Ludwig and Loebell[34]) into the ureter of a dog, exhibited two chief variations of pressure. One of these depended upon the vermicular movement of the ureter; the momentary elevation thus produced rarely exceeded 4 inches of mercury. But the second, which was more constantly visible, amounted to a positive pressure of from ·28 to ·39 inches. We cannot from hence conclude, that the latter extremes really correspond to the varying tension under which the urine passes into the commencement of the urinary tubules, since they may be assisted by slight contractions of the ureter, and perhaps also of the calyces and pelvis of the kidney. But it may be conjectured that the original pressure is at least as great as these numbers would indicate.

941. The act of opening the lower orifice of the urinary bladder (above *z*, Fig. 175), forms the next step in the evacuation of the urine. The first impulse to this is probably given by the *compressor urethræ* of the membranous urethra (*z*, Fig. 154), which is provided with striped muscular fibres (Tab. IV. Fig. 54). This is followed by the relaxation of the *sphincter vesicæ* (above *z*). The several bundles of unstriped fibres in the fundus and body of the bladder (*m n*) compress this receptacle, so that the urine is driven forth through the urethra (*z a b*), as through the

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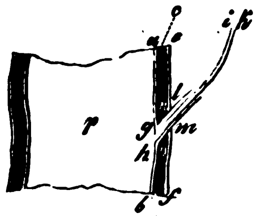
canula of a syringe. The mode in which the ureters (*n*) penetrate the bladder prevents all hurtful retrogression of the fluid at this period. For instance, supposing *g h i k*, Fig. 155, to be the lowest part of the ureter, it passes for a certain distance between the muscular bundles, *n*, *o*, of the bladder, before opening into its cavity. When these bundles contract, they instantly close the terminal segment of the ureter, *g h l m*.

FIG. 155.



942. Since the male has a longer and narrower urethra than the female, the width, form, and velocity of the stream of urine (*z* to *f'*, Fig. 154), differ in the two sexes. But in both, the abdominal pressure assists, (§ 393) when any difficulty occurs.

When the orifice leading to the urethra is obstructed, urine collects in the bladder in constantly increasing quantities. The bladder thus becomes so distended, that its fundus (*m*, Fig. 154) ascends into the umbilical region (from *v* beyond *x*, Fig. 9, p. 34). In such cases it finally bursts in some part of its extent, generally below, where it is not covered by peritoneum (comp. Fig. 9). The urine is thus effused in the neighbouring areolar tissue; the scrotum and penis swell considerably; and inflammation, gangrene, and death, shortly follow.

In rare instances, nature seeks another and a less dangerous outlet. In the embryo a hollow duct, the urachus (*d*, Fig. 119, p. 208), runs from the fundus of the bladder towards the navel, and from thence passes to the membranes of the ovum. It is subsequently converted into a solid cord. In some cases of retention of urine, it has happened that this remnant of the former urachus, or the umbilical ligament of the bladder, has opened afresh, and the urine has gushed out at the navel (ϑ, Fig. 9, p. 34).

943. In the bladder, the urine probably becomes denser and more mucous. But since all the quantitative analyses of this fluid have been made upon urine which was evacuated from the body, this circumstance must be borne in mind in considering the numerical estimates.

944. The specific gravity of the urine may vary from 1004 to 1050: the usual average seems to be from 1015 to 1019. The quantity of water which it contains is from 92 to 99 per cent. Since, in the course of the day, many watery substances are introduced into the alimentary canal, the urine, and especially that which is passed after drinking (*urina potûs*), is more watery than that which comes away on arising in the morning (*urina sanguinis*). That which is evacuated during the digestion of solid food (*urina cibi*) is generally between the two former in this respect. But neither the specific gravity, nor the amount of water, allows us to judge of the nature of the solid residuum; since its several constituents vary remarkably in quantity.

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945. Under ordinary circumstances, the urine may give off more water than the pulmonary or cutaneous evaporation. We have seen (§ 836), that these removed somewhat less than 2lbs. 8⅝ oz. from the author's body daily. The average quantity of urine in the twenty-four hours was 3lbs. $3\frac{1}{8}$ oz. Taking its watery constituent at 94·6 per cent, we obtain 3lbs. and ⅓ oz. of water. It is obvious, that even a moderate increase in the transpiration would suffice to reverse this relation. Thus Barral gives 40·4 to 45·5 oz. of water as the quantity lost from his body by evaporation in twenty-four hours, and only 34·5 to 41·4 for the urine.

946. The fresh urine of mammalia gives off a certain quantity of carbonic acid on coming into contact with the air. The details of this gaseous interchange require a further examination. From causes with which we have already (§ 327) become acquainted, the putrefying urine frequently contains free ammonia, or its carbonate.

947. The urine contains a mechanical admixture of vesical mucus (§ 880), and fragments of epithelium (Tab. II. Fig. 31). In addition to this, its concentrated residue and ashes exhibit the following substances: urea; uric acid; hippuric acid (§ 521); kreatin (§ 321); oxalates, carbonates, phosphates, and sulphates; sulphurets and chlorides of the metals; silicic acid; iron; and manganese. To these may be added a colouring matter; some peculiar (and probably variable) mixed substances which are as yet little known, and are included under the name of extractive matters; and sometimes, compounds of fluorine. Blood, pus, semen, and fragments of various tissues, constitute its morbid mechanical admixtures: and sugar, butyric acid, albumen, and unusual red and blue colouring matters, its abnormal chemical constituents. Besides these, a great variety of substances may appear in the urine as a result of their being taken in the food.

948. The percentage composition of the urine varies so considerably from all these circumstances, that it is scarcely possible to talk of averages of its several constituents. We have no complete analyses of urine which correspond to the recent progress of science. Hence we will only quote an older example for the sake of its completeness. Lehmann found in human urine 93·2 per cent. of water, 3·29 of urea, ·11 of uric acid, ·15 of free lactic acid (kreatin with other substances), 1·15 of extractive matters, ·01 of vesical mucus, ·73 of sulphate of potash and soda, ·4 of phosphate of soda and acid phosphate of ammonia, ·37 of chloride of sodium and ammonium, ·11 of phosphate of lime and magnesia, and ·17 of lactic salts.

949. A part of the urea is due to the fact, that the elements of this compound are formed by the ordinary vital functions, and especially by the locomotive organs; and are then dismissed as effete from the blood into the urine. A second portion arises from the metamorphosis of

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the digested azotized food, and especially of the albuminous substances. Hence the amount of urea is diminished in fasting animals, and rises considerably after the use of highly azotized food, such as eggs or meat. With vegetable diet its quantity is less, while muscular activity remarkably augments it.

950. Since the quantity of uric acid is much smaller than that of urea (§ 948), it is far more influenced by any errors of analysis. This fact, together with the considerable variations which seem to occur under similar collateral circumstances, explains the obscurity which attaches to the relations of uric acid to the changes of the organism. The quantity of uric acid in the urine is sometimes visibly increased by the continuous use of a meat diet.

951. The observations instituted by Lehmann upon himself will explain much of what has just been said. This observer found as follows :—

Accompanying Circumstances.	Average daily Quantities.							Proportion of Urea to solid Residuum.
	Per cent.			Absolute Weight in Grains.				
	Solid Residuum.	Urea.	Uric Acid.	Total Quantity of Urine.	Solid Residue.	Urea.	Uric Acid.	
During 14 days only the necessary food and drink was taken. Two hours' movement daily in the open air .	6·412	3·072	·112	16336·7	1047·4	501·9	18·27	1:2·09
Animal food only during 12 days .	7·272	4·424	·123	18571·4	1350·4	821·6	22·83	1:1·64
Exclusively vegetable food for 12 days	6·517	2·473	·112	14038·6	914·8	347·2	15·77	1:2·64
Food absolutely free from nitrogen for two days . . .					643·7	232·4	11·35	1:2·71

952. The urine of well-fed carnivora contains considerable quantities of urea. While, according to Frerichs, dogs fed upon substances devoid of nitrogen give off about the same quantities of urea as in the fasting state. The quantity thus secreted is that produced by the functions indispensable to life.

953. According to Lecanu, men give off, on an average, 432·4 grains of urea : according to Becquerel only 295 grains. The latter observer estimates the quantity for women to be 270·3 and 240·9 grains. Lecanu found 125· for old age; and 69·5 to 208·5 for the latter part of childhood.

954. We have already seen (§ 322) that urea contains more nitrogen

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than any other organic compound (46·73 per cent). It therefore conveys large quantities of this element out of the organism. The 432 grains of urea contain 201 of nitrogen; and the 270 grains, 108. Barral estimates the nitrogenous constituent of the proper mixed food of adult men as amounting to from 324 to 432 grains daily.

955. Small quantities of urea are often present in other fluids besides the urine. In spite of the presence of albuminous substances (§ 297), it may be recognized in the blood. It is also frequently found in morbid exsudations (such as dropsical effusions); in the aqueous humour, and vitreous substance, of the eye; and according to some, may rarely be met with in the saliva and other secretions.

956. These facts justify the conclusion, that the urea of the urine is not produced in the kidneys, but transudes from the blood. These glands do but permit it to pass unchanged into their secreted product; while the others either reject it, or immediately decompose it, so that it can no longer be recognized.

957. The fact that the blood contains but very small quantities of urea speaks rather for, than against, this theory. For when we consider the large quantity of blood which circulates daily through the kidneys, it becomes evident that if the blood contained much, and was only partially unloaded in the urinary organs, the urine would contain more urea than it does. A simple calculation will corroborate this statement.

If the urine of a person exclusively fed on meat gives off an average of 821 grains of urea in the 24 hours, this gives ·57 grains as the mean quantity per minute. Assuming both kidneys together weigh from 3850 to 7700 grains, more than 770 grains of blood would pass through these glands in one minute. But taking only 770 grains, the blood would require but ·07 per cent to contain ·57 grains of urea. And recollecting that part of the urea is retained by the albumen of the blood, and lost by precipitation with nitric acid, we shall not be surprised to find that only traces of it are discoverable.

958. In the urine of man and carnivora the quantity of uric acid is small. In the herbivora, its presence is exceptional, and its amount still smaller. But a large quantity is found in the mixed fæces and urine of birds and snakes. When treated with oxidizing substances, it is converted into other organic compounds allied to it. The action of nitric acid produces alloxan, alloxanthin or parabanic acid, and urea; treatment with potash and ferrocyanide of potassium, carbonic acid, allantoin and urea; and finally, with peroxide of lead, carbonic and oxalic acids, allantoin, and urea. We shall hereafter find that many of these metamorphoses occur in the living body; and that the urea possibly thus originates in the blood.

959. Hippuric (or, as it was formerly called, uro-benzoic) acid may

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not only be found in the urine of the horse and cow, but also in that of the human subject at all ages. In certain morbid circumstances, as for instance in many cases of diabetes or chorea, its quantity is greatly increased. And after the ingestion of benzoic acid, cinnamic acid, oil of bitter almonds, or benzoic æther, these substances are found in the urine as hippuric acid.

960. If hippuric acid be boiled for some time with dilute sulphuric, hydrochloric, nitric, or oxalic acid, or with soda or potash, it is decomposed into benzoic acid and glycocoll or glycin (§ 319). The latter substance we have also found appearing in the after-changes of the cholic acid of the bile (§ 926).

961. The presence of lactic acid in the urine was formerly deduced from the fact that the salts of zinc gave a crystalline precipitate. But Heintz and Pettenkofer found that this deposit contains kreatin and kreatinin (§ 319); the same compounds which may be obtained from broth, and from the cold watery extract of striped muscle (Tab. IV. Fig. 54). The later researches of Heintz indicate that kreatin is only an after product, and is not originally present.

962. What are called the extractive matters of the urine form a variable mixture of different compounds. The colouring matter which may be separated from them by acetate of lead contains, according to Scherer, 56·6 to 61·3 per cent of carbon, 4·1 to 6·2 per cent of hydrogen, 6·3 to 7· per cent of nitrogen, and 33· to 25·5 per cent of oxygen.

963. The nature and amount of the salts are necessarily subject to great variety, since many soluble substances of this kind which are introduced with the food pass, changed or unchanged, into the urine. If proper saline solutions be injected into the blood, this phenomenon generally occurs still more rapidly. For instance, Vierordt and Wellzien introduced 1375 grains of salt, dissolved in 18·6 cubic inches of water, into the jugular vein of a horse, in the course of 25 minutes. Thirty minutes later, 6·1 cubic inches of urine contained 11· grains of salt; an hour later, 10·92 grains; and 1½ hours later, 11·98 grains. While 6·1 cubic inches of healthy urine only offered ·15 to ·23 grains.

964. The most careful analysis of the ashes of the food will not fully explain the circumstances now under consideration. For it is probable that the meroxygenous (§ 295) constituents of the food and urine are unequal in quantity. The general appellation of animal or vegetable food is evidently yet more uncertain. One can, at most, but conjecture, from reasons hereafter to be mentioned, that the quantity of sulphates and phosphates may be increased by a diet of meat or eggs. This opinion is supported by some experiments instituted by Lehmann on himself. He found as follows :—

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Accompanying circumstances.	Average daily Quantities.						
	Proportions per cent.			Absolute amount in Grains.			
	Phosphate of Soda.	Phosphates of the Earths.	Sulphates of the Alkalis.	Total Quantity of Urine.	Phosphate of Soda.	Phosphates of the Earths.	Sulphates of the Alkalis.
None but necessary food and drink for 14 days. Two hours' daily movement in the open air	·347	·104	·664	16336·7	56·73	16·94	108·51
Purely animal food during 14 days .	·451	·296	·865	18571·4	83·72	55·01	160·6

965. Bodily exercise increases the alkaline phosphates of the urinary residuum. The quantity of earthy phosphates in the urine of fasting men is but small. According to Lehmann, it is increased in this state,—according to Bence Jones, it is not. The urine of carnivora contains much phosphates; while that of herbivora contains but little, sometimes mere traces. But on the other hand, the urine of the latter presents more carbonates. In the urine of children, the quantity of the alkaline phosphates is also diminished.

966. Oxalate of lime (Tab. I. Fig. 3) is frequently found in the urine of perfectly healthy persons. Its quantity may be increased by the use of vegetable substances containing oxalates, as well as by many peculiar and unusual changes of the uric acid (§ 958) of the blood or other tissues. According to Donné, champagne produces the same effect.

967. Sugar taken in moderate quantities does not re-appear in the urine. But if a larger amount be introduced into the stomach or the blood, part of it is found in the urine. In saccharine diuresis or *diabetes mellitus*, the urine, which is secreted in abnormal quantity, contains sugar. This kind of sugar, which formerly received the special appellation of diabetic sugar, corresponds in all respects with grape-sugar.

968. Different methods have been used to show the saccharine contents of the urine. Rotation of the plane of polarization (§§ 173, 256) can, at most, only indicate the fact, and not decide it. The fermentation-test formerly adopted, can only be practised when a large quantity of sugar is present. Besides this, it is very deceptive, since carbonic acid, or carbonate of ammonia, may be given off by other constituents of the urine. In applying this test, the urine, mixed with yeast, is introduced into a flask *a* (Fig. 156), from which passes off a tube, *b*, into a vessel, *c*, partially filled with lime-water. This is connected by a second tube, *d*, with an open flask, *e*, also containing lime-water. The lime in *e* attracts to itself the carbonic acid of the atmosphere (§ 795), so as to

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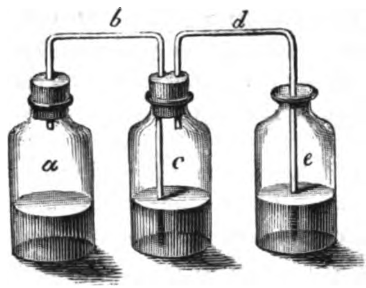
maintain the lime-water contained in *c* in a state of purity. On bringing the whole apparatus into a warm place, a lively fermentation is soon set up. The carbonic acid set free at *a*, passes through *b* towards *c*, causing a white precipitate of carbonate of lime to be thrown down here.

FIG. 156



When sugary urine undergoes fermentation, numerous yeast-plants (Tab. II. Fig. 30) are frequently found in it. But the presence of this vegetable fungus is no infallible sign that the urine contains sugar.

When sugary urine is boiled with a solution of caustic potash, the whole acquires a red-brown colour. The application of nitric acid then produces an agreeable odour of treacle. Trommer's test depends upon the fact that, during or after boiling, grape-sugar reduces oxide of copper which has been precipitated from a solution of its sulphate by an alkali. We thence get a yellowish or reddish colour of the precipitate. According to Fehling, this test may even be used to determine the quantity of sugar contained in the urine. A vessel (Fig. 157) having a graduated capacity, and provided with a tube of outlet, is filled with a watery solution, 100 cubic inches of which contain 1012 grains of sulphate of copper, 4050 grains of tartrate of potash, and 14,172 grains of soda ley of sp. gr. 1·12. Another similar tube receives a portion of the urine, diluted with 9 to 19 times its quantity of water. We now pour one cubic inch of the copper solution into four cubic inches of water, boil the mixture, and drop urine from the second tube, until no red precipitate is produced. A cubic inch of this copper solution corresponds to 1·46 grains of grape-sugar. Larger quantities of sugar may be extracted by alcohol.

FIG. 157.

969. Urine containing sugar may often be distinguished by its high specific gravity (1030 to 1060), and by the large quantity (6 to 12 per cent) of its solid residuum. The quantity of sugar in the urine is

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increased by a diet of hydrates of carbon (§ 303). Hence it has frequently been attempted to feed diabetic patients upon meat only. But, as a rule, this treatment is unsuccessful. The exclusively meat-diet becomes unbearable after a time. Besides this, the urine never loses the whole of its sugar, probably because grape-sugar can be produced from the nitrogenized compounds.

970. The urine of many consumptive patients frequently contains large quantities of fat: and, on standing, often deposits oil-globules on its surface. Something similar to this occurs in patients suffering from other diseases; where considerable quantities of fat may also be discharged with the fæces.

971. In persons of weak constitution or debauched habits, boiling the urine often throws down, not only a whitish powder of carbonate of lime, but also flocculi of albumen, which do not disappear on the application of nitric acid. This fact is best observed in the urine evacuated some time after a meal. And in a variety of diseases—such as inflammation, diseased heart, and dropsy—the urine sometimes contains large quantities of albumen. Hence this phenomenon forms no exclusive sign of that affection of the kidney which is usually designated by the name of Bright's disease. In this disorder, the urine generally contains, not only albumen, but also minute masses of fibrine, which in shape resemble sausages.*

When but little albumen is present, no flocculi are deposited by boiling,—especially if the urine is either originally alkaline (§ 972) or has acquired this reaction from its spontaneous decomposition. And since white salts of lime are also precipitated by boiling, the urine should always be mixed with a small quantity of nitric acid, and carefully heated.

972. Fresh human urine has generally an acid reaction. But the nature of the food may give rise to different results. We shall see that the constituents of many kinds of food (especially of vegetables) reappear in the urine as alkaline carbonates. If these are present in large quantity, the urine is originally alkaline. When the acid urine undergoes spontaneous decomposition, it also becomes alkaline, from the gradual conversion of its urea into carbonate of ammonia (§ 327). Hence, in diseases of the spinal cord, where the urine is passed involuntarily, we often find that the soiled linen of the patient is soaked with a fluid of an alkaline reaction, and ammoniacal odour. But even in these instances, the fresh urine is acid.

The urine of carnivora is acid, while that of well-fed herbivora is alkaline. The urine of the horse is mixed with a great number of minute crystalline globules (Tab. II. Fig. 20). These, which may be collected in pounds on a filter, also occur in the urine of the cow, the pig, the rat, and sometimes the mouse and rabbit. They consist chiefly of

* These are casts of the urinary tubules.—EDITOR.

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carbonate of lime and magnesia, united with a small quantity of an organic substance. But if an herbivorous animal be made to fast, its urine becomes acid, since it only consumes its own flesh. Hence the alkaline character of the urine depends on the nature of the food.

A fact observed by Liebig may serve to indicate the cause of the acid character of the urine of man and carnivora. We have seen (§ 965) that the urine of these animals contains a considerable quantity of alkaline phosphates—compounds of which only traces are found in the urine of herbivorous animals. Pure uric acid is only soluble in water with extreme difficulty. According to Bensch, one part requires from 1800 to 1900 parts of boiling water, and from 14,000 to 15,000 at 68°. While a solution of bibasic phosphate of soda takes up hippuric acid even when cold, and uric acid when warm. It thus acquires an acid reaction, if sufficient uric acid be present. On subsequently cooling, a part of the uric acid is again precipitated. We shall soon find that the urine frequently offers a similar phenomenon.

973. The researches of Woehler, and the corrections since furnished by himself and Frerichs, accurately inform us which of the substances taken into the alimentary canal are transferred—changed or unchanged—to the urine. We have already (§ 959) learnt what substances reappear as hippuric acid. When the neutral salts of the vegetable acids are introduced into the blood, either immediately, or through the stomach, they are converted into carbonates. They undergo combustion at the expense of the oxygen of inspiration (§ 270). Oxalic, citric, malic, tartaric, and succinic acid, reappear in the urine in this form, in union with bases. Tannic acid is converted into gallic and pyrogallic acids, and substances allied to *humus*. The following substances reappear in the urine:—indigo, gamboge, the colouring matter of madder, logwood, beet-root, bilberries; the odorous principle of valerian, asafœtida, garlic, castor, saffron, and turpentine; certain compounds of opium; the narcotizing principle of toadstools; together with carbonate, chlorate, nitrate, and sulphocyanate of potash; ferrocyanide, and sulphocyanide of potassium; borax, chloride of barium, silicate of potash, and potassio-tartrate of nickel. But this is not the case with the compounds of alcohol, ether, camphor, Dippel's animal oil, resins, the colouring matter of chlorophyll, litmus, alkanet, and cochineal. Sulphuret of potassium reappears, partly in this form, partly as sulphate of potash. Iodine is converted into alkaline iodides: ferridcyanide, into ferrocyanide, of potassium.

Quinine frequently passes off in the urine, but caffein (§ 343) does not. Salicine is probably metamorphosed into spiric or spiræic acids; and phlorrhizin into hippuric acid, and oxalate of lime. Oil of bitter almonds containing no hydrocyanic acid, is converted into benzoic acid, and thence into hippuric acid. By taking urate of potash or urate of ammonia, the quantity of urea is increased. Hence the uric acid is

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probably converted into urea by oxydation (§ 958). Rhodallin (or ammoniated oil of mustard) furnishes sulphocyanide of ammonium, as it does after being heated with soda and lime. Most of the metals—such as gold, silver, iron, lead, tin, bismuth, arsenic, and mercury, — are occasionally carried off in greater or smaller quantities with the urine.

974. The experiments instituted by Stehberger and Erichsen on persons with extroversion of the bladder (§ 939) show that traces of the substances introduced with the food soon appear in the urine. Under the most favourable circumstances, ferrocyanide of potassium only required an interval of one minute; while the colouring matter of indigo or madder demanded a quarter of an hour. This velocity is explained by the rapidity of the circulation (§ 717), and by the way in which suitable solutions transude porous animal membranes (§ 146). When the stomach is filled with food, the ferrocyanide of potassium appears in the urine much more slowly.

975. Urine left to itself sooner or later deposits a sediment. The mucus and epithelium mixed with it frequently separate during cooling. The fresh or concentrated urine subsequently precipitates uric acid (Tab. I. Fig. 2), oxalate of lime (Tab. I. Fig. 3), carbonate of lime — chiefly in the form of fine granules, — and ammoniaco-phosphate of magnesia (Tab. I. Fig. 17, *i k l*). Sometimes this deposit occurs spontaneously; sometimes only after the application of hydrochloric acid, or other reagents. In the urine of diseased subjects large quantities of such deposits are frequently found. The red brick-dust sediment of feverous subjects chiefly consists of uric acid, generally in the form of minute tables (Tab. I. Fig. 2); and of alkaline and earthy urates. The colour of the whole is produced by a peculiar red matter, of the nature of which little is known. In other cases these salts of lime and magnesia are mixed with a large number of mucous corpuscles (Tab. II. Fig. 31, *d*), blood-corpuscles (Tab. II. Fig. 24, *a*), pus-corpuscles (like those in Tab. II. Fig. 23, *c*), and spermatozoa (Tab. V. Fig. 79).

976. Urinary calculi may be produced in any part of the urinary organs. Most frequently they arise in the bladder. For since the urine remains in it for some time, solids which are but little soluble are most easily deposited here. The presence of a solid nucleus of any kind greatly favours their deposition. A lump of mucus, a grain of sand, a small stone, a straw, or a piece of metal which has accidentally penetrated from without, may form the kernel around which new layers successively arrange themselves.

977. The lithic or uric calculi chiefly consist of uric acid and the insoluble urates. The oxalic calculi consist in great part of oxalate of lime; and the phosphatic, of combinations of phosphoric acid with lime and magnesia. With these other substances are frequently mixed. The

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nucleus often consists of uric acid, or urate and oxalate of lime; while the external rind is formed of earthy phosphates.

978. The absence, degeneration, or removal, of one kidney does not necessarily give rise to any important disturbance. But dogs, cats, and rabbits, from whom both have been excised, die at latest in a few days. The operation is followed by fever, loss of appetite, depression, and sometimes diarrhœa. Death is frequently preceded by convulsions. The quantity of urea contained in the blood is probably much increased. Most of the secretions appear to be more watery than usual; and frequently contain compounds of ammonia. The fluid exsudations sometimes met with in the abdominal and thoracic cavity generally contain large quantities of urea or carbonate of ammonia.

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CHAPTER XII.

THE VASCULAR GLANDS.

979. The class of glands indicated by the above name includes the spleen (*g*, Fig. 75, p. 132), the supra-renal capsules (*a b*, Fig. 154, p. 285), the thyroid (*e*, Fig. 101, p. 187), and the thymus (*d*, Fig. 100, p. 186), glands. Many observers, such as Ecker, add to these the pituitary body.

But this class includes organs of very different structure and functions. The supra-renal capsule, the thyroid, and the thymus, at least so far correspond to each other as that they all consist of closed tubes, which otherwise resemble the ducts of the glands, and contain cells, nuclei, and other solid structures. They may therefore, with a certain degree of correctness, be called glands without ducts. But the anatomy of the spleen is so different, as to assign it quite a different office. Still the functions of all the structures now reckoned amongst the vascular glands remain almost unknown.

980. The strong fibrous membrane that clothes the *spleen* is prolonged into its interior: giving off sheaths, which surround the branches of the arteries (see Fig. 158), and unite with each other so as to form a network. These enveloping structures contain unstriped muscular fibres (Tab. IV. Fig. 69), together with the ordinary areolar and elastic fibres.

Fig. 158.

Fig. 159.

According to Ecker, the muscular fibres in the human trabecular tissue consist of fibre-cells, having nuclei which are appended laterally, as shown in Fig. 159. By the aid of the rotatory electro-magnetic apparatus, R. Wagner, Koelliker, and Ecker, have succeeded in producing contractions of the surface of the spleen in the dog and cat: while Harless has obtained the same result in an executed criminal.

981. The branches of the arteries distributed in the interior of the spleen are occupied by peculiar roundish vesicles, the Malpighian or

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splenic corpuscles. The situation of these, as seen under a low magnifying power, is represented in Figs. 160 and 161. They contain a colourless fluid, which rarely coagulates in the air, together with cells and free nuclei. They frequently collapse after death. On this account they

FIG. 160.

FIG. 161.

are sometimes missing, especially if the vessels of the spleen are not tied before its removal. Their connection with the vessels and absorbents has not yet been definitely made out.

982. According to Ecker, the small arteries which ramify in the neighbourhood of the splenic corpuscles, or elsewhere, are afterwards continued into a delicate capillary network distributed in the spleen-pulp. But, hitherto, he has not been able to observe the transition of these capillaries into veins. Many of the latter vessels have distinct dilatations. They form meshes, which somewhat resemble those in the corpus cavernosum of the penis. Finally, as regards the absorbents, we are as yet only acquainted with those larger vessels which emerge from the spleen, or are distributed upon its surface. Their relations in its interior have not been observed.

983. The spleen-pulp is the more or less red and pulpy substance which is seen on cutting up the organ. According to Ecker, it contains nuclei; cells; single or aggregated blood-corpuscles (Tab. II. Fig. 24); cells which enclose blood-corpuscles; and yellow or colourless granules and masses, either free, or surrounded by cells.

984. It was formerly conjectured that new blood-corpuscles were produced in the spleen. This view was especially supported by the fact, that the absorbents of oxen killed during the digestive process are filled with a reddish lymph, in which blood-corpuscles are revealed by the microscope. And some observers consider that the cells just mentioned as filled with blood-corpuscles (§ 983) furnish additional support to this theory,—the blood-corpuscles being produced in these cells, and afterwards set free by their solution. But since other cells include solid structures, which gradually lose their definite form, many believe that precisely the reverse process obtains—that the blood-corpuscles undergo destruction in the spleen. They suppose that clusters of them are enclosed in cells, are next converted into these yellow masses, then break up into granules, and finally disappear.

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985. According to the concurrent statements of many anatomists, the cells which enclose blood-corpuscles, as well as the other transitional forms just mentioned, are found, not only in the spleen, but also in abnormal effusions of blood in the brain, liver, and kidneys. Hence their presence is not an appearance peculiar to the spleen. It may even be questioned whether it is normal, or whether it is the direct result of accidental injury to the delicate parenchyma of the organ. At present a decision of the whole question is impossible.

986. Recently, J. Beclard has stated, that the blood of the splenic vein in the dog and horse contains a much smaller quantity of corpuscles than that of the subclavian vein. According to him, the former contains from 8·18 to 16·14 per cent of blood-corpuscles, while the latter has from 9·83 to 18·51 per cent. If these differences were not suspiciously large, they might be regarded as proving the decay of blood-corpuscles in the spleen.

987. The spleen has often been noticed to exhibit an extraordinary increase of volume some hours after feeding. Dogs live unhurt a long time after the extirpation of this organ. The voracity, emaciation, and alteration of the sexual impulses, which have been remarked in such cases by some observers, have not been found by others.

988. The *supra-renal capsules* are distinguished by their comparatively large size in the new-born infant (*r*, Fig. 119, p. 208), and their still greater size in the earlier embryo. According to Ecker, they consist chiefly of closed tubes; which lie close to each other, contain a fluid, nuclei, and a number of fine granules, and are surrounded by a dense capillary network. The cortical substance of older human subjects contains bodies such as are represented by Tab. V. Fig. 67. An extraordinary number of nerves enters this organ. But many only pass through their tissue, to be distributed to other structures. It is probable that certain compounds secreted from the blood undergo a peculiar elaboration in these tubes. But the object of this function is as yet unknown; nor are we even acquainted with the means by which the altered substances are rendered useful to the other organs of the body. At present the theories formerly advanced—that the function of the supra-renal capsules is closely related to that of the cerebral, urinary, or sexual, organs—rest upon no secure basis of facts.

989. The *thyroid gland* contains a great number of lobules, separated from each other by areolar tissue. Imbedded in these we again find tubes, containing a fluid, and nuclear structures, which, according to Ecker, are apposed to the limitary membrane in the form of a pavement, as represented in Fig. 162. We may sometimes see simple cells, as indicated in Fig. 163;—and in the dog these are often double. A rich network of capillaries surrounds the several lobules of the gland.

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990. The degeneration of the thyroid so frequently met with, and the safety with which it may be extirpated, plainly forbid us to assign it any function essential to life. Dogs sustain the simultaneous loss of thyroid and spleen without any perceptible mischief.

FIG. 162.

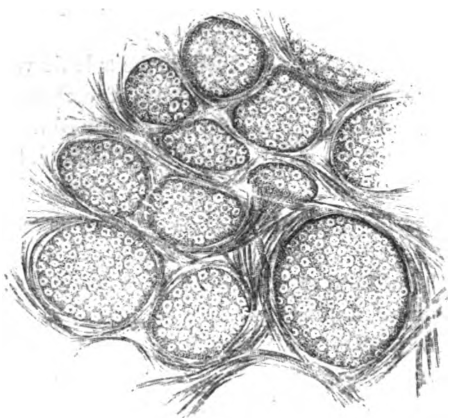
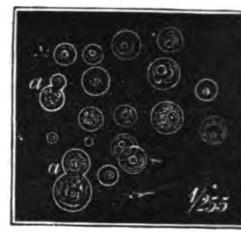


FIG. 163.



991. The anatomy of the thyroid gland indicates that certain substances are deposited and changed in its tubes. But all the exertions of its numerous investigators have been unable to substantiate anything beyond this. It is frequently stated that the thyroid enlarges after violent screaming, parturition, or coïtus. But these facts are not only exceptional, but inconclusive. And the theory that the thyroid is closely related to the brain, to the organs of voice, or of respiration, is devoid of all satisfactory foundation.

992. The wen or goître is a degeneration of this vascular gland. Its tubes frequently become distended with foreign substances, or gelatinous deposits, which greatly increase its total bulk. The vesicles thus produced often form the greater part or the whole of the organ. In these we often find cells, which are distended with this gelatinous substance; together with fat globules, and crystals of cholesterine, which are visible to the naked eye as glittering points or scales, and are exhibited, highly magnified, in Fig. 164. In many cases the blood-vessels are themselves enlarged, so as to form globular dilatations—such as we shall again meet with in treating of the function of nutrition. In others, we find effusions of blood, exsudations, and deposits of cholesterine, or earthy substances. Finally, considerable lengths of the smaller vessels, or walls of the vesicles, may become more or less calcified: the first of these appearances is represented five times magnified (after Ecker) in Fig. 165. We may judge of this vast increase of size by the fact, that while many wens

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weigh more than 2 pounds, the healthy thyroid body weighs but $\frac{2}{8}$ to $\frac{4}{8}$ths of an ounce.

FIG. 164.

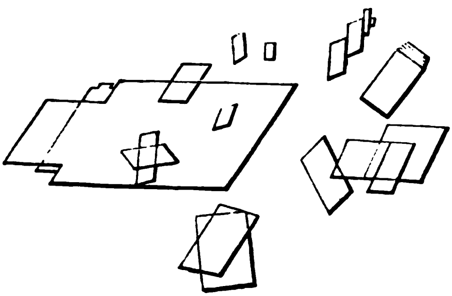
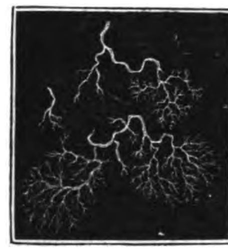


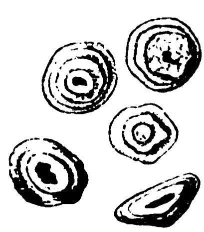
FIG. 165.



993. The *thymus* attains a large size in the embryo; but reaches its greatest bulk in the earlier years of childhood. It then becomes stationary; and is subsequently converted into a peculiar fatty mass, in which form it sometimes persists to the end of manhood. If we cut through the areolar tissue and vessels which pass between its lobules, each half may be unrolled like a spirally coiled ribbon, as shown (after Ecker) in Fig. 166. Each consists of a number of small vesicles or tubes seated upon a central canal; the cavity of which is immediately continued into their interior. Thus this organ offers a greater resemblance to the arborescent glands than the supra-renal capsules or the thyroid.

FIG. 166.

FIG. 167.



994. The vesicles of the thymus contain a clear fluid, with nuclei, and rarely cells. Ecker found peculiar concentric structures, enclosing a fatty substance. Similar appearances are seen in the fat of embryos which have been kept in alcohol. And in fibrinous coagula of the heart Hassall has noticed similar substances (Fig. 167), which offer a concentric lamination.

995. We have seen that the final destiny of the thymus is a metamorphosis into fat. According to Ecker, this change may occur in new-

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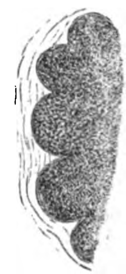
born infants, or children under two years of age. Thus, while under a high magnifying power, the margin of a lobule of healthy thymus offers the appearance represented in Fig. 168, fragments of the altered organ look like Fig. 169. Masses of aggregated fat-globules make the whole still more opaque, and almost black by transmitted light.*

Fig. 168.

Fig. 169.



996. We may suppose that the thymus also forms a kind of laboratory for the elaboration of matter. Its great development in early life indicates that its chief use belongs to this age. From this we might conjecture, though not conclude, that its function is related to the milk-diet of the suckling.† Young mammalia in whom Restelli had extirpated the thymus showed an extraordinary voracity, and many unusual cravings for food. They emaciated rapidly, and died much more quickly than other animals, who had suffered equally considerable wounds without the removal of this organ.

* The medical reader should, however, remember that this is not the change finally undergone by the healthy thymus. Here we have not merely fatty molecules, but fat-cells, or adipose tissue.—Editor.

† A conjecture which, as pointed out by Mr. Simon, is sufficiently refuted by his discovery of the thymus in birds and reptiles.—Editor.

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CHAPTER XIII.

NUTRITION.

997. The phenomena of nutrition may be considered under three chief sections:—a *morphological;* relating to the several changes which are undergone by the tissues, and are visible with or without the aid of the microscope: a *numerical;** which concerns those changes of weight experienced by the whole body, and the several organs: and, finally, a *chemical;* which treats of the changes of combination gradually undergone by the constituents of the organism. Since the state of these factors during the advance or retrogression of the organized being forms the history of development, the study of nutrition only requires us to consider it as merely maintaining its own existence.

998. *Morphological Phenomena of Nutrition.*—Since the absorbents constantly transmit lymph (Tab. II. Fig. 22, *a*) and blood-corpuscles (Tab. II. Fig. 24, *a*) to the blood, this fluid would gradually become overladen with solid structures, if other of its mechanical elements were not destroyed. We are therefore entitled to infer, that the balance is maintained by a continuous cycle in the development of blood-corpuscles. The colourless corpuscles are gradually converted into coloured ones (Tab. II. Fig. 24, *b c*); while the oldest of these disappear by solution, or otherwise.

999. The way in which this occurs has not yet been established. We have seen that there is no sufficient foundation for the views according to which the liver (§ 928) or the spleen (§ 984) would form the site of this solution of the older blood-corpuscles. Since extirpation of the spleen produces little or no disturbance of the vital functions, we are justified in conjecturing that this vascular gland does not, at any rate, exclusively fulfil the important office of diminishing the number of blood-corpuscles. It may rather be supposed, that the changes undergone by the blood in the different channels of the circulation themselves maintain the counterpoise. The balance would thus be maintained in the blood itself, instead of being exclusively connected with any special organ. Under these circumstances, respiration and nutrition

* Here, as well as in § 1078, the above word has been substituted for "statistical;" a modern term, which ought to be limited to what it connotes,—viz. matters directly relating to the *state*. See Dr. Guy's able article "Vital Statistics," in the "Cyclopædia of Anatomy."—Editor.

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would form the chief conditions for the development of blood-corpuscles. The statement — that those of the frog (Tab. II. Fig. 23, *a b*) are dissolved by alternately transmitting oxygen and carbonic acid through the blood,—appears to be incorrect.

1000. The proportion of colourless corpuscles (Tab. II. Fig. 23, *c*, Fig. 24, *b c*) varies with the condition of the body, and with the character of the blood. According to Donders and Moleschott,[35]) their number is increased some time after a meal. Eleven hours and a half after the last meal, the blood contained, on an average, 5·1 lymph-corpuscles (Tab. II. Fig. 24, *b c*), to 2000 coloured ones (Tab. II. Fig. 24). While three hours after the midday meal, their number rose to 6·2. According to Remak, when an animal loses large quantities of blood in succession, the paler blood contains a disproportionately large number of colourless corpuscles. According to Virchow, in the human subject this obtains to such an extent, that it may be mistaken for pus in the blood. As regards the retrogression of blood-corpuscles, it would seem that those which contain distinct nuclei (Tab. II. Fig. 23, *b*) at the highest point of their development, lose them before being destroyed.

1001. The blood which circulates in the vessels is a mechanical mixture of homogeneous *liquor sanguinis* with the varieties of blood-corpuscle (*a c d*, Fig. 114, p. 200) just mentioned. The coagulation seen in the blood taken from a vein, consists in the fact, that a certain quantity of solid fibrine separates itself from the liquor sanguinis, and entangles the blood-corpuscles which, owing to their greater specific gravity, are falling to the bottom. In this way we get a leathery substance, the clot or *crassamentum*, and a yellowish green or reddish fluid, the *serum*, of the blood. The former is therefore a mixture of blood-corpuscles and fibrine, soaked in blood; while the latter is what was formerly *liquor sanguinis*, deprived of its fibrine. Since the large amount of albumen contained in the serum gives it a certain viscidity, blood-corpuscles which have accidentally escaped entanglement in the fibrine, may remain floating in it.

1002. The chief cause of the red colour of the blood consists in the great number of its coloured corpuscles (§ 658). Under the microscope, which certainly diminishes colour, the liquor sanguinis is at most of a faint yellow. The fibrine separated by coagulation is yellowish-white or yellow. The intense red colour of the clot is explained by its mechanically enclosing the blood-corpuscles during coagulation.

1003. When the blood taken from a vein is allowed to rest, two processes occur. The heavier blood-corpuscles gradually descend. The specific gravity and viscidity of the liquor sanguinis or serum can but delay this movement. Besides this, solid fibrine is deposited from all points of the fluid. If these two occurrences tolerably coincide in point of time, the fibrinous masses will everywhere enclose blood-corpuscles. The whole of the clot will therefore have a red colour. But

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if, on the other hand, any cause delay coagulation, the corpuscles may sink before all the fibrine is deposited in a solid form. Hence it is only the deeper portions of fibrine which enclose many corpuscles; so that the clot is red below and in the middle, but yellow above.

1004. The upper yellow layer has been designated the buffy or inflammatory coat, because it is found in blood removed by venesection in inflammatory disorders. But experience teaches that it is often absent during inflammation, and present under other circumstances—as, for instance, during pregnancy. From what has been just mentioned, it is obvious that, by delaying coagulation, it may be produced artificially. A protraction of the process of cooling—such as may be produced by receiving the blood into warm wooden vessels (§ 202)—or the addition of a certain quantity of potash, soda, carbonate of soda, or sulphate of magnesia, is always sufficient to produce a buffy coat. And should any cause diminish the specific gravity or viscidity of the serum, while the blood-corpuscles retain their ordinary number and specific gravity, it is obvious that a similar result will follow.

1005. At first, the clot forms almost the whole mass of the blood. Afterwards, it gradually contracts, and thus loses part of the serum which was mechanically united with it. Hence the separation of the coagulated blood into a large solid mass, and a fluid, is the result of an after process. And if the blood forms a thin layer, so as to offer a comparatively large surface for evaporation, this distinct separation does not occur. When large quantities of blood are left to themselves, the coagulum subsequently again softens, and finally becomes intimately mixed with the greater part of the putrefying serum.

1006. Under the microscope, the coagulated fibrine is a yellow homogeneous mass; but is often disposed in folds, or broken up into streaks, so as to exhibit deceptive appearances of a fibrous structure (Tab. II. Fig. 25, *a*). When small fragments of it are torn up in serum, we sometimes see flat scales (Fig. 170), such as are designated by Nasse, fibrine-flakes. The corpuscles represented in Fig. 167, occur very rarely. Now and then the fibrine is mixed with granules, oil-globules, and very minute structures which glitter like crystals (§ 176) in the dark field of the polarizing microscope (§ 172).

FIG. 170.

1007. The coloured blood-corpuscles of mammalia are originally circular flat discs, with excavated surfaces (Tab. II. Fig. 24, *a*). Hence, standing on their edges, they look like a small ribbon tapering at its middle (Tab. II. Fig. 24, above and to the right of *a*). The colourless corpuscles are more or less globular (Tab. IV. Fig. 24, *b c*); so that they offer much the same shape in all positions. When the liquor sanguinis is diluted with water, so as to

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diminish its density and the proportion of its saline contents, the coloured corpuscles take up water, and give off part of their colouring matter to the surrounding fluid. They thus become swoln, pale, and globular (Tab. II. Fig. 25, *b c*). The proper application of salt sometimes restores their previous flattened form.

1008. Since the liquor sanguinis is thinned by the separation of its fibrine, some of the blood-corpuscles it contains frequently exhibit a globular form. Others, which retain their flat form, are often apposed to each other by their surfaces, like a rouleau of coins (Tab. II. Fig. 24, *c d*). On examining fresh blood from an incised wound of the finger, we sometimes see that lively currents spring up in the fluid, and tear up these rouleaus into fragments, while threads of half-coagulated fibrine are drawn out from between them. The blood-corpuscles are easily wrinkled into radiating folds; and by more complete drying, they become star-shaped.

1009. The medical jurist frequently has to determine whether red stains on linen, furniture, or cutting instruments, are due to human blood. Where but small quantities are concerned, chemical examination cannot afford any trustworthy results; since the blood does not contain any characteristic and peculiar substances, and its small amount of iron furnishes no indication. A microscopic examination is often equally inconclusive. If the blood-stain is to be extracted with a watery fluid, we must not select pure water, but a liquid which, like a solution of salt or sugar, does not affect the forms of the blood-corpuscles. If these exhibit oval forms (Tab. II. Fig. 23, *a b*) it will follow that the blood does not come from man, or any domestic animal, but from a bird, fish, or reptile. If their shape be spherical, they may belong to some fishes, the domestic mammalia, or man. But there are generally insuperable difficulties in deciding whether they are those of a man or a mammal. It has certainly been maintained that the medical jurist may be guided by the smallness of the structures remarked under the microscope. But apart from the circumstance that smallness of diameter may be due to previous desiccation, we must remember that the average diameter of the human blood-corpuscle equals 1-3560th of an inch, while that of the dog is 1-3330th, the cat 1-4400th, the pig 1-4220th, the horse 1-4720th, the ass 1-4010th, the cow 1-4320th, the sheep 1-5310th, and the goat 1-6350th. Hence, even under the most favourable circumstances, we could only recognise the blood of some of the mammalia, such as the domestic ruminants: and should never be really entitled to affirm that we had human blood before us.

1010. We shall hereafter see that it is the blood which sustains the phenomena of nutrition; that it sets apart the substances necessary to the tissues, and takes up compounds which have become unfit for their use, either directly, or by means of the absorbents (§ 534). It is therefore

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obvious, that all parts of the organism require blood-vessels for their maintenance and growth.

1011. The non-vascular tissues,—such as the epidermis (Tab. IV. Fig. 62, *a b*), the nails, the hairs, the epithelium, and, generally, all the horny tissues,—contain in their interior neither blood-vessels nor nerves. Hence they may be wounded without exciting hæmorrhage or pain. But the vascular parts are permeated by numerous vessels; and, for the most part, by nerves also. Hence their mechanical injury is followed by hæmorrhage, and frequently by pain.

1012. The substances required by the non-vascular tissues, are furnished by their matrix, *i.e.*, by the vascular tissues in their immediate neighbourhood. While, conversely, the vascular structures derive them immediately from the blood-vessels which run in their own mass. Still this difference is, in many respects, less important than might at first sight appear.

1013. For instance, on examining a villus of the small intestine, such as is represented by the diagram (Fig. 171), we see that the nutritional substances required by the non-vascular cylinders of epithelium (*a*) will be supplied by the remote capillary network of the matrix (*d*). While the remainder of the substance of the villus, which belongs to the tissues called vascular, possesses no other capillaries, than those indicated at *d*. Hence all parts of it not in immediate contact with the vessels (*d*) are compelled to derive the combinations they require from the nutritional fluid, which is everywhere present, and is constantly renewed by the blood. Since even the finest vessels surround a certain number of primitive nerve-fibres, a quantity of areolar tissue, &c., the same observations will apply to these structures. In all the tissues, the nutritional fluid in which they are soaked forms the path by which the necessary substances reach them, and others leave them to enter the blood.

FIG. 171.

1014. Since the vascular tissues are surrounded on all sides by a network of capillaries, and are thoroughly steeped in nutritional fluid, this path will, in their case, be shorter, and the mixture more uniform. But in the thicker horny tissues this is not the case. Since the matrix of the hair (Tab. IV. Fig. 63, *d*) occupies the bottom of the cavity of skin from which it grows, the compounds which are to reach the point of the hair have to pass through a considerable distance. Let 1, 2, 3, 4, (Fig. 172) represent the separate layers of the epidermis; 1 being the most superficial, and 4 the deepest, which is immediately bounded by

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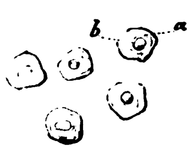
the matrix. Here it is evident that only those substances rejected by 4, can reach 3, and only those refused by 3, can arrive at 2—and so on. Hence every layer has a more limited selection, according to its distance from the matrix. But it is obvious that something of the same kind must occur, to a less extent, with the vascular tissues.

FIG. 172.

1015. The denser horny tissues—such as the cuticle, the nails, and the hairs,—are subject to a constant and more or less active integral renovation, even in adults. Let us suppose that the epidermis existing at any given time, consisted of the layers, 1, 2, 3, Fig. 172; the uppermost stratum of which is usually set free in the form of scales (Tab. IV. Fig. 62, *c*). These are so small, that their desquamation generally eludes the naked eye. But if a finger be kept many weeks bandaged in linen, a mealy-looking mass will be found, which consists solely of desquamated epidermis. While 1 thus disappears, the new layer, 4, is produced below; so that the cuticle now consists of the layers 2, 3, 4. It therefore loses none of its absolute thickness. And as the process is continually repeated, the person has, after some time, a totally different skin from that which he formerly possessed.

1016. If we investigate these changes with the aid of the microscope, we see that the soft layer of cuticle which immediately limits the corium, developes nuclei, enclosed in delicate cells. These afterwards lose their albuminous contents, and become flattened, while their coats are partially hornified. They then acquire an appearance resembling that represented in Tab. II. Fig. 33. They are finally converted into very thin horny scales, which sometimes appear elevated in the region of the thicker (but now clear) nucleus, *b*, Fig. 173. If the hornifying process is carried still further, the nucleus becomes indistinct, or disappears (Tab. II. Fig. 32). The oldest horny scales of epidermis are at length dismissed from the organism by the process just mentioned (§ 1015).

FIG. 173.



During this development of the horny cells, the desquamation of the epidermis by layers is constantly pressing them forward towards the surface; so that the oldest cells of the cuticle are found in this situation (Tab. IV. Fig. 62, *a c*), while the youngest occupy the region of the *rete Malpighii* which adjoins the corium (Tab. IV. Fig. 62, *b*).

1017. Pressure acting on the skin exerts a visible influence upon the thickness of the epidermic strata, and the degree in which they become horny. The difference between the rough hand of a smith, and the tender one of a lady, is in part thus explained. But it would be wrong to apply this theory universally. It is true that the thickest cuticle

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occupies the heel (Tab. IV. Fig. 62), which is also the place where the weight of the body rests in standing. But this part of the cuticle is thicker even in the embryo;—a fact which proves that the peculiarity essentially depends upon the original plan of organization.

1018. Many pavement-epithelia,—for instance, those of the tongue and mouth—also consist of various layers, from which the older and more superficial are constantly being shed. This explains why every drop of saliva contains a number of thin horny scales (Tab. II. Fig. 31, *a b*). The same phenomena are exhibited in a less remarkable degree by other more delicate varieties of pavement-epithelium—such as the conjunctiva of the eye (Tab. II. Fig. 23), the nuclei of which are larger and more granular, while their walls become less horny. Younger cells (*a*, Fig. 174) also lie under those ciliated columns (*b*, Fig. 174 and Tab. II. Fig. 36), which we meet with in the respiratory passages. But this desquamation is not so regular as that which occurs in the pavement-epithelia above mentioned.

FIG. 174.

1019. Under the microscope, a thin section of the free margin of the nail shows an indistinctly granular grey mass, which is traversed by irregular, and frequently zig-zag, lines of fission (Tab. II. Fig. 37). If the whole be soaked for some time in sulphuric acid, or boiled in a solution of caustic potash or soda, we find that the semi-fluid mass contains a number of transparent horny scales (Tab. II. Fig. 38). And a careful examination teaches us that, however much the substance of the horny nail appears, at first sight, to differ from the cuticle, it is still entirely composed of horny cells, united to each other by a solid cement. The lines mentioned above are merely clefts, which have been produced by cutting away the brittle mass; they rarely indicate true super-imposed layers.

1020. The matrix of the nail lies underneath its surface. It forms elevations and depressions, which resemble those seen in the skin at the end of the finger, but take a straighter course. Large vascular loops (comp. Fig. 110, p. 199, and Tab. IV. Fig. 52, *e*) run in the interior of these moulds, which essentially correspond with the rows of tactile papillæ (Tab. IV. Fig. 62, *d e*) on the rest of the skin. From hence are secreted the younger nail-cells. Still the substance of the nail is thinner at the root than further forwards. Its white spots sometimes show that it grows slowly forwards from the root, so that the oldest segment finally projects beyond the neighbouring soft tissues.

1021. The horny shaft of the hair (Tab. IV. Fig. 63, *c*) consists of three parts. Around its outer surface lie thin epithelial scales, which overlap each other like the tiles of a roof, so that their margins form

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transverse lines (Tab. II. Fig. 39, *a*). Occasionally, some of them are partially stripped off; and project from it, either alone, or in connection with oil-globules, and accidental impurities (Tab. II. Fig. 39, *e*). Under the thin cuticle (*b*) is the striated cortical substance, which forms the greater part of the hair (Fig. 39, *b*). This first tears up into fibrous bands; and may then, with the aid of sulphuric acid, be separated into small, thin, horny scales. Finally, in the middle is often seen the medullary canal, filled with pigment (Fig. 39, *c*). But in some places it is frequently absent, or, at any rate, does not enclose pigment (Fig. 39, between *c* and *d*). Here and there paler patches of pigment also occur (Fig. 39, *d*).

1022. In grey hair, the colour of the cortical substance is whitish grey; in flaxen hair, it is yellow; in red hair, it varies from yellowish red to reddish; and in brown or black hair, it is light or dark brown. The uniform colour of this cortical part always has its effect. Still many of the hairs appear darker to the naked eye; either on account of the large quantity of pigment enclosed in their highly developed medullary canal, or from numerous small deposits of pigment in their cortical substance, or from both of these circumstances together. Such scattered patches of pigment are the chief cause of the change of flaxen hair into brown as adult age advances: since it is only later that the cortical substance alters in colour. While, on the other hand, the alteration which makes the hair grey appears to attack this part of it first.

1023. That segment of the horny part of a hair which is concealed by the skin (Tab. IV. Fig. 63, *c d*) is fixed into a peculiar sac, the hair-bulb (*e f g*). Its sides are surrounded by a double coat; the outer and inner root-sheath of Henle (*e* and *f*). These are special processes, sent inwards from the deeper and superficial layers of the epidermis (*a b*). The middle layer of the hair-bulb contains, according to Koelliker, unstriped muscular fibres (Tab. IV. Fig. 59), which pass round it in circles.

1024. That segment of the shaft which is fixed in the hair-bulb frequently enlarges at its lower extremity (Tab. IV. Fig. 63, *d*); while, in other instances, it is more or less pointed. The elements of the cortical substance here experience a transition into horny cells, which are younger, the deeper they are followed; and finally, they merge into nuclei and cell-formations, which are secreted from the matrix—*i. e.*, from the blood of the vessels which here surround the hair-bulb. In this way the hair is pushed upwards from below. The subsequent cells apply to their further development the materials which have been left by their predecessors.

1025. What has just been stated sufficiently shows, that many of the most important phenomena of nutrition and growth depend on the character of the matrix of these dense horny tissues. Thus, while cutting the hair not only does not injure it, but may even, from obvious reasons,

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further its growth, destruction of its lower germinal part or matrix leads to baldness. Such an injury may be produced by general internal diseases, by cutaneous eruptions, or by the growth of fungi in the bulbs.

1026. It cannot be doubted that the vascular tissues undergo a thorough change in the course of time. But few, if any, of them exhibit rapid and regular changes. Many indeed appear to remain stable during a very long time.

1027. The quantity of fat varies greatly with the state of nutrition. In corpulent persons, the masses of fat which lie beneath the skin, in the mesentery, on the surface of the heart and great vessels, between the muscles, and in the neighbourhood of the nerves, are considerably increased. All these deposits consist of the ordinary fat-cells (Tab. II. Fig. 27). And, conversely, in sick persons who are much emaciated, we sometimes find beneath the skin nucleated cells, which only contain one or more oil-drops. Similar alteratious are also found in dropsical subjects. But many masses of fat which have an important relation to muscular actions—such as the fat of the orbit or the cheek—do not disappear in the most emaciated subject. We shall presently see that, even in starvation, the fatty substances of the brain and spinal cord, and probably those of the nerves, are retained.

1028. The pigments are closely related to the fats. In the choroid of the eye, they have a definite physiological use. Thus it is only in albinos—like the white rabbit—that these cells of the choroid (Tab. II. Fig. 29) contain no black molecules of pigment (Tab. II. Fig. 28). Here they are of a greyish white colour. In such persons there is a general absence of dark pigment. Hence their white or whitish flaxen hair, their clear blue irides, and pale yellow faces.

1029. Under various normal or abnormal conditions molecules of pigment are frequently deposited, either free or enclosed in cells. Thus in the bodies of men and animals, we sometimes find branched pigment-cells (Tab. II. Fig. 30) occupying the neighbourhood of the blood-vessels, the nerves, the ganglia, and the cerebral and spinal dura mater; while, in other instances, they are absent from all these points. And in various kinds of tumours, considerable quantities of pigment are often produced, giving rise to black discolorations, which are called melanoses.

1030. Fat and pigment are frequent supplementary products of the hornifying process. The deposits of pigment met with in the hairs (§ 1022), and the dark tint of the skin (which chiefly depends upon the epidermis), are partially referable to this cause. The black colour of the negro depends exclusively on the epidermis, and chiefly on its youngest and deepest layers. Here Krause has found pigment-cells, together with a large quantity of dark brown nuclear structures.

1031. Just as the quantity of adipose tissue is increased in corpulence,

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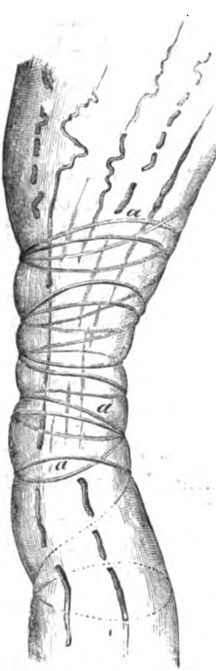
so muscles, strengthened by good food and exercise, increase in size, and especially in diameter. But microscopic research teaches that the striped fibres (Tab. IV. Fig. 54) of a strong labourer, and those of a weak emaciated girl, do not essentially differ in thickness: or, at any rate, not sufficiently so to explain the enlargement of the total muscular mass as due to that of its several elements. From this it follows that, when a person becomes more muscular from continuous labour or gymnastic exercise, new muscular fibres are gradually produced.* We are justified in conjecturing that something similar occurs with the nerve-fibres. Still the thickness of the nervous trunks does not experience so remarkable an increase as that of the muscles.

1032. Many vascular organs of the adult possess certain structures, which appear to indicate earlier stages of development. The denser substance of the crystalline lens of the eye consists of peculiar fibrous structures of various size, called lenticular fibres (Tab. IV. Figs. 56 and 57). A semi-fluid mass, the liquor Morgagni, is found between the solid lens and the capsule which encloses it. It contains a number of globules (Tab. IV. Fig. 55) resembling the elements of the first deposits of lenticular substance in the embryo. Many cartilages contain simple cartilage-corpuscles at their circumference, and compound ones towards their middle. The striped muscular fibres (Tab. IV. Fig. 54, *b*) possess a membrane, the myolemma or sarcolemma, on the surface of which may be remarked numerous nuclei. When the bundles of areolar tissue (Tab. III. Fig. 40) are treated with acetic acid, the whole becomes gelatinous, transparent, and homogeneous (Tab. III. Fig. 41, *a*). At the same time, there appear certain peculiar fibres (Tab. III. Fig. 41, *b*) much akin to the elastic fibres (Tab. III. Fig. 42, 44). These sometimes encircle the bundle of areolar tissue, in the manner represented, after Henle, in Fig. 175. But some of them are imperfect, and seem to consist of a number of elongated nuclei, which are arranged in longitudinal series at certain distances from each other. This may be illustrated by the upper half of Fig. 175.

FIG. 175.



* But the bulk of a limb is sometimes increased by exercise so rapidly, that we may doubt whether there has been time for that development of a complex muscular and tendinous apparatus which every new fibre would imply. And although the great range of diameter in the fibres of the same subject obscures calculation, still when a very slight difference is multiplied by the enormous number of these in the muscular thickness of a limb, it seems sufficient to account for the altered bulk. It is, however, by no means unlikely that the original number of fibres differs greatly in different individuals.—EDITOR.

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Similar nuclei and cells are found in the earlier development of the embryo. Hence the occurrence of these structures in the adult admits of two interpretations. We may either regard them as indicating a continuous integral renovation of substance; or may view them as organs which, from collateral circumstances, are less completely developed than their neighbours. The latter idea seems nearest the truth.

1033. In various healthy or morbid conditions, large quantities of ashy constituents, and especially of calcareous salts, are deposited in the cartilaginous or fibrous tissues. The process of ossification — *i.e.*, of transition into true bone—consists, not merely in the copious deposit of these inorganic compounds, but also in the simultaneous occurrence of definite structural changes. Where the hardened mass is devoid of true osseous structure, the process is often distinguished by the special name of calcification, or earthy transformation.

1034. True bone is produced from cartilage. This consists of a basis of intercellular substance (Tab. III. Fig. 45, *a*), in which are imbedded the cartilage-corpuscles (*b c d*). They form simple (*c*) or compound cells (*b c d*); the walls of which are frequently thickened, and form parent-cells enclosing smaller ones. The latter frequently possess cavities (*e*), the dark margins of which make them look like isolated oil-globules at first sight.

1035. According to H. Meyer,[36] cartilage ossifies in two ways. In all those cartilages which are bones in the adult, the intercellular substance becomes earthy before the corpuscles. But where centres of ossification are deposited in the nasal, thyroid, and costal cartilages, or in the fibro-cartilages, the reverse of this process obtains.

1036. When we examine a thin section of an ossifying long bone—for instance, the tibia of an infant—under a low magnifying power, the corpuscles of the cartilage in the neighbourhood of the bony substance (Tab. IV. Fig. 51, *b c*) are seen to be aggregated in clusters (*a b*), which are often arranged lengthwise in rows, that have a direction (*d e*) identical with that of the osseous partitions already produced (*b c*). A higher magnifying power shows that the several groups of cartilage-corpuscles correspond with secondary cells, which are contained in parent-cells. This circumstance, however, is not essential to the ossifying process: many of the embryonic cartilages contain only simple cartilage-cells.

1037. The calcareous salts are first deposited in the intercellular substance that extends between the cells of the cartilage. Although they are chemically united with this substance, still we frequently see a few fine calcareous molecules, which agglomerate in many places, and finally become inseparably confused with the rest of the osseous mass. In this way are produced balks or partitions of bone (Tab. IV. Fig. 51, *b c*); which, at one end, are connected with each other, and at the other,

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protrude their simple or forked branches (*b e*) into the neighbouring cartilage. They enclose between them the simple or compound cells of the cartilage. Where medullary cavities (*f*) are produced, these cells gradually disappear, together with the substance by which they are surrounded. But, when not thus removed, the greater part of their substance also becomes earthy. There remains only the central cavity (corresponding to *e*, Tab. III. Fig. 45), which sends branches into the thickening walls, and becomes converted into a corpuscle or *lacuna* (Tab. III. Fig. 47, *e*, and Fig. 50, *b c d c*) of the permanent bone.

1038. In the second mode of deposit just mentioned, the calcareous granules are deposited in the walls and interior of the cartilage-cells. Frequently they also become fused into a continuous mass. If the intercellular substance is converted into bone, the fine granular deposit is repeated on the outer surface of the cell-wall (compare Tab. III. Fig. 45, *b c d e*).

1039. On examining a thin section of perfectly developed bone under a low magnifying power, we find that its compact tissue (Tab. III. Fig. 46, *a*) consists of a number of cavities (*b*)—the medullary or Haversian canals—and numerous small structures (*c*),—the corpuscles or *lacunæ*. Under a powerful lens, such a transverse section from the human femur shows the round or oval orifices of the Haversian canals which have been cut across (Tab. III. Fig. 47, *b*). Many of these, which pass obliquely downwards (*c*), are also seen in a part of their length. A longitudinal section of the bone frequently affords a side view of these cavities (Tab. III. Fig. 47, *a*). In the compact or cortical substance which forms the outer surface of most bones, they possess a smaller diameter. While, conversely, in the internal spongy or medullary tissue, these canals are larger than their intervening osseous partitions.

1040. Transverse sections of the compact tissue show that the Haversian canals are encircled by concentric layers of bone (Tab. III. Fig. 47, *d*); while the thinner bony partitions of the cancellated tissue are devoid of this arrangement. The lacunæ (Tab. III. Fig. 47, *e*, Fig. 48, *b c*), which, in the first of these substances, are also placed concentrically, give off on all sides (Tab. III. Fig. 48, *d*) minute tubes or *canaliculi;* which unite with each other, and, in some places, form an independent network. Although they often appear black by transmitted, and white by reflected light, still during life they usually contain a fluid, without calcareous granules. In some of the lacunæ, however, the latter may occur. Still, when a few lacunæ are included in a very thin lamina of bone, they are generally clear and transparent: so that we may easily convince ourselves of the absence of all mechanical deposit of calcareous salts.

1041. The medullary cavities are clothed by the medullary membrane,

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and possess blood-vessels, which pervade the interior of the bone. Where they form large cavities, the additional space thus acquired is occupied by a deposit of fat-cells (Tab. II. Fig. 27), the aggregation of which forms what is called the marrow. But these contents do not entirely fill the medullary cavity. It may therefore be conjectured that, in the living animal, the vacant space is occupied by watery vapour, and probably by other elastic fluids. And just as the surface of these internal cavities of the bone is covered by the medullary membrane, so its outer surface is clothed by another fibrous tunic, the periosteum.

1042. When cartilage is converted into bone by the process just (§ 1036) mentioned, none but cancellated or spongy substance is at first produced. In very young bones this extends to their surface. The process is subsequently completed in two ways. New bone is secreted beneath the periosteum. And the several rods of bone are also enlarged by the deposit of additional strata. Upon this fact the concentric arrangement of its layers chiefly depends.

1043. Many have supposed that the bones and teeth are subject to an uninterrupted integral renovation. This opinion is based upon the results of feeding animals with madder. Thus if the food of a young pigeon or pig be mixed with madder, after some time the bones will be found of a rose-red colour. But if the food mixed with madder, and the ordinary food, are given during alternate weeks, the bones are afterwards found to contain some red layers, and other white ones. Many observers have therefore assumed that these portions of the bone were new productions, gradually formed by constant integral renovation: that the red layers corresponded to the times during which the food had been mixed with the madder; and the white, to the intervals of simpler food. They supposed that the new bone was chiefly deposited by the periosteum; and the old absorbed by the medullary membrane. Hence the renovation of the osseous substance proceeded from without inwards. But in the teeth it took the reverse course. That part of the true dentine which lies internally, and is apposed to the vascular and nervous tooth-pulp (Tab. III. Fig. 49, *a*) was the youngest; and that (*b*) which bordered on the enamel (*b c*) the oldest. Hence it was only the true dentine (Tab. III. Fig. 49, *a d b*) provided with tubes and bony cement, which took the red colour: the enamel did not do so.

But such observations do not prove a rapid and continuous change of these hard tissues. The colouring matter of the madder enters the blood; the liquor sanguinis of which thus acquires a red hue. It easily combines with salts of lime; as may be shown by artificial experiments. Hence those parts of the bones and teeth which are in immediate propinquity to the blood-vessels become coloured red. Microscopic research supports this proposition. When the coloured food is stopped, the red portions resume their yellowish colour. And those parts

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which lie next to the vessels are again situated most favourably for the occurrence of the change. And in point of fact, a microscopic examination shows, that the whiter strata do not consist of new layers, but of portions which have lost their previous colour. The varying colour is best seen in young animals whose bones have not yet finished their growth.

1044. It cannot be doubted that slow changes occur in the bones and teeth, as in the other parts of the body. In old people the proportion of cancellated tissue is increased. Chossat fed poultry upon grain unmixed with gravel, and found that the bones became gradually thinner, and hence more brittle and flexible. If a rodent,—as for instance, a mouse,—be imprisoned for months without a possibility of gnawing anything, his incisor teeth grow out, become curved, and even penetrate the jaw-bone by their extremities.

1045. The intercellular substance of young cartilage appears almost homogeneous. But in many of the articular and other cartilages of the adult, it exhibits a granular or fibro-granular structure (Tab. III. Fig. 45, *a*). The fibro-cartilages lead us a step further. Here the intercellular substance consists exclusively of fibres, in the intervals of which lie the cartilage-corpuscles. In the later years of life it sometimes happens, that not only the intercellular substance, but also most of the cells, of the previous true cartilage, are in certain places converted into fibres. And conversely, the whole sometimes softens, and either remains gelatinous, or finally disappears, so as to give rise to the formation of cavities.

1046. Congestion and inflammation are caused by certain disturbances of circulation and nutrition. It is supposed that a part in a state of active congestion is permeated by too large a quantity of blood, while in passive repletion this fluid becomes permanently aggregated in its interior. The cerebral hæmorrhage which causes the apoplectic stroke is intimately connected with such morbid conditions of the circulation.

1047. Hitherto the microscopic phenomena of commencing inflammation have chiefly been investigated in the web of the frog's foot (§ 651). These animals—together with many other reptiles and fishes—offer the advantage of allowing their circulation to be examined without the infliction of any injury of importance. Still such observations only afford very imperfect results; since in these creatures, inflammation takes a more sluggish course, and the subsequent exsudation is but sparing in quantity. Warm-blooded animals, such as bats, are better suited to such microscopical examinations.

1048. If any point of the extended frog's web be burnt with a hot iron, or moistened with a drop of mineral acid, the blood-corpuscles (*c*, Fig. 114, p. 200) in the neighbourhood of the wounded place are sometimes seen to quicken their speed. But soon afterwards the blood within a certain distance becomes completely obstructed. At first sight, the ves-

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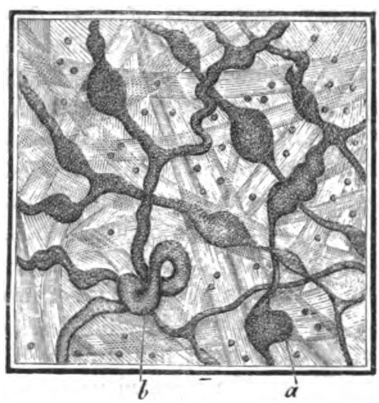
sels seem to be dilated. But a peculiar circumstance here deceives us. The small side-space (*a*, Fig. 114) which was formerly the immovable layer, (§ 656), and was chiefly occupied by colourless liquor sanguinis, now contains numerous blood-corpuscles; so that the whole vessel is redder, and appears wider. But no genuine increase of diameter can at first be established by the micrometer: at least not in the web of the frog's foot.

1049. In the mammalia, all the smaller vessels of the inflamed part become considerably distended with blood. This fact explains the intense red colour seen in inflammation. It is probable that when this over-distension of the vessels has lasted some time, their transverse diameter increases. It has been sometimes remarked by Hasse, Koelliker, Ecker, Harting, and myself, that—in inflamed portions of brain, thyroid gland, bronchi, and ovaries,—many of the vessels are dilated like those represented (from a diseased ovary after Harting) in Fig. 176. Finally, the

FIG. 176.



observations of Hasse and A. Mueller on the smaller cerebral vessels of apoplectic subjects showed that their internal membranes had burst in many places, and had allowed blood to be effused between them and the external tunics. A series of dilatations were thus produced; which, unlike those in Fig. 176, were not formed by the whole of the vessel.

1050. The vessels filled with obstructed blood contain an unusual number of coloured corpuscles (§ 658). The way in which the circulation sometimes returns to its normal condition has already been described (§ 661). But if this fails to occur, the whole coagulates into a red granular mass; in which the several blood-corpuscles gradually lose their distinctness. At the same time the resistance offered by this immovable mass exposes the coats of the neighbouring vessels to a more or less increased pressure. Hence a fluid is copiously effused, and forces its

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way into the neighbouring tissues. We thus get an exsudation; which distends the tissues, and produces a swelling.

1051. But all exsudations are not produced by the phenomena of inflammation just mentioned: since they may also be caused by a very watery state of the blood, by an abnormal porosity of the vessels, too strong a pressure of the blood, or a want of the corresponding lymphatic absorption (§ 534). The character of these, as well as of inflammatory, exsudations, varies with the circumstances of the particular case.

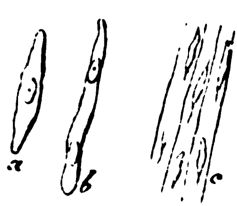
1052. The exsudations which form the majority of dropsical effusions generally maintain their liquid form both during life and after death. They usually contain more or less albumen, yellow colouring matter, salts, and sometimes urea. The fluid removed by tapping a patient with ascites rarely deposits a fibrinous coagulum. But many inflammatory exsudations deposit solid matters even in the living body. These frequently form a gelatinous mass, which is easily thrown into folds, or tears irregularly. Granules of albumen, or globules of fat, may frequently be found on or between them by the aid of the microscope.

1053. The elementary constituents of other deposits of this kind exhibit a higher development. They contain what are called exsudation-corpuscles, inflammatory globules, or granule-cells (Tab. II. Fig. 25, *d*): *i.e.* granular and spherical cells, which consist of a transparent membrane enclosing minute granules. Water causes many of them to burst; and makes the nuclei of others more distinct. Under the influence of acetic acid, the nuclei become indented, so as to exhibit separate divisions. This phenomenon, which also occurs in other similar cells, has been designated the cleavage of the nucleus.

1054. In the fresh and pure exsudations of many animals, these corpuscles are sometimes surrounded by clear rings, or cells, which the application of water causes to burst like soap-bubbles. It is probable that this observation will never be repeated upon the exsudations of the human subject, since these are always injured by a previous mixture.

1055. Where the exsudation undergoes a further development, we remark longitudinal striæ; which possess, either a single elongated nucleus (Fig. 177, *a*), or several nuclei at definite distances from each other (Fig. 177, *b*). Subsequently these are often narrowed and elongated. They next become paler; and finally, altogether disappear. The fibrous bands become more solid; and their most minute constituents are then formed by fibres like those of the areolar tissue (Tab. III. Fig. 40). In this way are produced the fibres of cicatrization, by means of which wounds are healed up. They are distinguished by their great strength, which enables them to unite separated parts with extreme tenacity.

FIG. 177.



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1056. Pus is a peculiar degeneration of the exudation. It consists of a fluid basis, the *liquor puris;* with which are mechanically mixed numerous peculiar solid structures, the pus-corpuscles. These essentially correspond with the exudation corpuscles already described (§ 1053). But they sometimes exhibit a rather yellower colour under moderate magnifying powers; and chemical examination indicates that they contain a larger quantity of fat.

1057. The fluid of *ichor* or of thin sanious pus, exhibits important differences from that of the ordinary thick, yellow—or, as it is called, *laudable*—pus. It possesses more or less corrosive properties; in consequence of which it acts injuriously upon many of the accompanying pus-corpuscles, as well as on the constituents of the tissues in which it is present.

1058. In order that a suppurating wound should heal, the suppuration itself must decrease. Hence the production of pus is a round-about way; which involves a loss of time, and of a certain quantity of the corporeal juices. On this account, wherever circumstances will at all allow it, we strive to heal wounds by the more rapid union "by first intention"; in which the exudation proceeds at once to the formation of a cicatrix.

1059. A suppurating wound which is about to close first secretes a smaller quantity of liquor puris: in which the corpuscles are sometimes heaped together like a precipitate. These, either alone or mixed with the relics of the disturbed tissues, form a kind of plug. The exudation-corpuscles, which subsequently replace the previous pus-corpuscles, are frequently aggregated into luxuriant papillæ: these are called granulations, or, when of improper quality, "proud flesh." The remainder of the process essentially resembles that by the first intention.

1060. Mortification or gangrene constitutes another termination of inflammation. This morbid affection of nutrition is usually caused by a deficient transmission of blood to the part, or by certain poisoned states of the fluid. The parts lose their colour, and frequently become as black as coal; and either dry up like the flesh of a mummy, or become liquified by putrefaction. The microscope often shows small black granules, which have been designated gangrene-corpuscles, and which, in many respects, resemble molecules of pigment (Tab. II. Fig. 28). These are generally mixed with greasy masses of blood; fragments of the tissues; fluid and semi-fluid exudations; and crystals, chiefly of ammoniaco-magnesian phosphates (Tab. I. Fig. 17, *k i l*).

1061. A part attacked by gangrene may be regarded as lost to the organism. The best termination therefore consists in the separation of the dead part by the establishment of suppuration in its neighbourhood, so as to leave a healthy wounded surface. Large portions of the body may thus be removed. For instance, it not only unfrequently happens that frozen feet separate spontaneously at a line of demarcation, which forms a circle of suppuration: leaving the surgeon nothing

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to do but to saw through the bones, in order to complete the amputation.

1062. When part of an organ has been lost in consequence of a wound, one of two cases may occur. In the course of time, the part which has been removed either is, or is not, reproduced. If we limit our attention to the higher animals, we find that many tissues possess a capacity of reproduction, which others are devoid of. But many of the lower animals can, under proper circumstances, reproduce all parts alike.

1063. A tissue which does not reproduce itself heals up by means of fibres of cicatrization. For instance, if a muscle has been cut through, portions taken from the seat of injury subsequently present microscopic appearances like those represented at Fig. 178. Its transversely striped fibres (*a*) cease abruptly; and the substance of the cicatrix (*b*) consists of the fibres described in § 1055. Something similar to this occurs in the skin, the mucous membranes, the cartilages, the brain and spinal cord, and most other tissues.

FIG. 178.

1064. The crystalline lens, the nerve-fibres, and the bones, belong to those parts which frequently reproduce themselves in the mammalia. The new tissues are here developed after laws which are essentially identical with those regulating their origin in the embryo.

1065. If the crystalline lens (Tab. I. Fig. 12) of a rabbit be extracted, leaving its capsule as nearly as possible uninjured, a new lens containing the ordinary lenticular fibres (Tab. IV. Figs. 56, 57) may gradually be produced. The disease called cataract consists in a cloudiness of the crystalline lens. This causes blindness by cutting off the transmission of the rays of light like a screen. Hence we

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seek to restore the sight, either by extracting the lens, or by pushing it into a place where it will not be in the way. It is only in very rare instances that a new lens is formed. But in persons previously operated on for cataract, many observers have found a substance which, to the naked eye, very much resembled that of the lens.

1066. On dividing a nerve, its two ends (*a* and *b*, Fig. 179) retract by their own elasticity, so as to leave between them a gap of variable extent (*c d*). If *c* and *d* remain opposite to each other, the interval, *c d*, is filled up by an exudation, which gradually undergoes a further development, and forms a lump (*c d*, Fig. 180) thicker than the rest of the nerve.

FIG. 179.

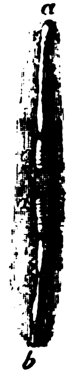

FIG. 180.

New nerve-fibres, which unite the old ones passing from *a* to *b*, are produced at *c d*. They proceed from the older portions of the nerve at these points; are at first grey, but subsequently contain true nervous matter; and are usually distinguished by their smaller diameter. The remainder of the knot is gradually converted into fibres of cicatrization (§ 1055). In the course of time, its size generally diminishes. And it may even happen that after some years, no trace of it can be found: or its site may be occupied by a constriction. The process just described may also occur when a piece has been cut out of the nerve.

1067. In order to this reproduction of nerve, the ends of the nerve-fibres must be opposed to each other, and the gap must not be too long. If one of the two portions be twisted, or otherwise so placed as not to afford any free cut surface which may originate the further growth, restoration will not occur. And even under the favourable circumstances mentioned above, it appears to be rare for all the primitive fibres to recover their previous condition.

1068. If the divided nerve be not reproduced, one or both of its ends may enlarge into a bulb, or may sprout into narrower portions, which are attached to neighbouring parts (compare *e*, Fig. 180). Many fibres of

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the peripheral segment subsequently lose their nervous medulla, become grey and pale, and in all probability finally disappear. This renders the whole nerve thinner, and gives it a dull greyish-white appearance. The central half, which is connected with the brain or spinal cord, is much less subject to this alteration; but some of its primitive fibres are also absorbed.

1069. Experiments on the free cervical ganglion of the vagus nerve in the rabbit show that the ganglion-corpuscles (Tab. V. Fig. 72) are also capable of reproducing themselves. In rare instances of disease, numerous pale ganglion-corpuscles may be met with in nerves which do not usually possess any.

1070. The union of fractures depends upon the capacity of bones for regeneration. A new substance, the *callus*, knits up the gap. It is generally more solid than the rest of the osseous substance: so that, if not injured by a morbid softening or attenuation, the bone yields in any part of its course rather than in the callus.

Fig. 181.

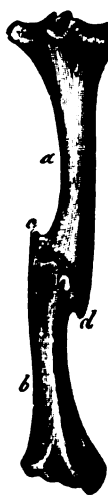
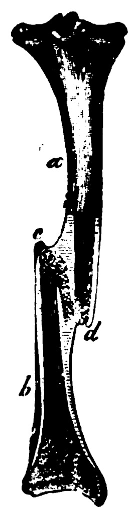


Fig. 182.



1071. When the tubular bone of a limb is completely broken across, the contraction of the muscles makes the two segments more or less overlap each other. The limb is therefore shortened. Hence it is the duty of the surgeon to restore the previous length by artificial extension, and to maintain it by splints or bandages until a callus of sufficient solidity is present. If this precaution be neglected or insufficiently carried out, the bones unite as they have overlapped; and the limb therefore remains shortened to a corresponding extent.

This latter condition may be illustrated by Fig. 181. It represents

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the shin-bone of an adult, which has united with a certain amount of shortening. The upper and lower fragments (*a* and *b*) overlap each other in the callus (*c d*). Fig. 182 exhibits the same bone partially sawn up, so as to expose the medullary canal of the two fragments (*a* and *b*) and the dense callus (*c d*) which unites them.

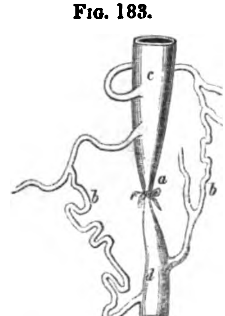
1072. The fracture itself ruptures some of the blood-vessels which run in the periosteum and the interior of the bone. Any further displacement of the ends of the bone wounds the neighbouring soft tissues. Both of these circumstances cause the effusion of a considerable quantity of blood in the parts surrounding the fracture; and subsequently this blood gradually coagulates. The effusion produced by the subsequent inflammation permeates and surrounds this extravasated blood, the colouring matter of which is gradually washed out prior to its own final disappearance by absorption. The exsudation meanwhile becomes cartilage. Bone is then developed, partly from the fractured extremities, partly in the rest of the mass, until finally the whole callus is completely ossified. It now generally appears thicker and rougher than the rest of the bone. But in course of time it is smoothed down by absorption; although, even after many years, it may still exhibit a greater bulk.

1073. The excretory ducts of many of the larger glands have a peculiar tendency to restore their channels. Even after the biliary duct of a living dog (between *m* and *r*, Fig. 151, p. 280) has been tied, the bile is sometimes again poured into the intestine (*i k*). The pancreatic duct (*p q*) may exhibit similar phenomena.

1074. On tying an artery in the middle of its course, it becomes filled with a thrombus or plug of coagulated blood, that extends to the neighbourhood of those collateral branches through which the circulation proceeds unimpeded. Here also there is an admixture of a new exsudation, which gradually produces fibres of cicatrization, while the coagulated blood in great part disappears. The portion of artery occupied by the plug finally becomes ligamentous, and is narrower than the rest of the tube.

1075. In the meantime the collateral circulation restores the movement of the blood, which had been checked or disturbed by the application of the ligature. The diagram in Fig. 183 may explain how this takes place. Let *a* be the ligature which prevents all direct flow of the blood from *c* to *d*. Large side-branches or collateral vessels, *b b*, are subsequently found to arise from *c*, and open into *e*. Thus the blood takes a roundabout course (*c b d*), and avoids the seat of deligation (*a*).

FIG. 183.



1076. It is probable that these collateral vessels originate in what were

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formerly minute anastomosing branches of the same artery. But the latter delicate tubes are not only mechanically dilated, but also acquire stronger coats, which finally correspond with those of the larger arteries.

1077. When vessels or nerves are amputated, many of these phenomena are partially repeated. This may be illustrated by the anatomy of a stump after amputation.

The stump of an amputated limb generally undergoes a considerable emaciation, which is usually greater in the upper arm or fore-arm than in the thigh or leg. In the most favourable instances the cicatrix forms a simple straight line. But in stumps formed by the upper part of the thigh, which have healed by suppuration, and possess a certain thickness, this scar is often radiating; so as to exhibit deep furrows, between which the other soft tissues protrude. Contraction of the muscles of one side may also remove it from its original place.

FIG. 184.

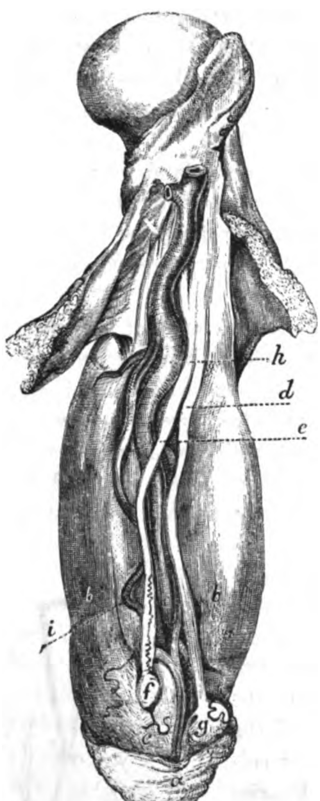

Fig. 184 shows the stump taken from a man whose left arm had been amputated about three years before death. At *a* are seen the folds of skin which occupy the neighbourhood of the cicatrix. The moderately thick muscles, *b b* (which have undergone a partial contraction), and the tendons, are attached by the tissues of the cicatrix, *c*, to the neighbouring structures. The larger nervous trunks, *d* and *e*, terminate in large bulbs, *f* and *g*, which are, however, solely composed of fibrous tissue (Tab. III. Fig. 40). Some fibrous bands pass from these swellings to the neighbouring structures. These bulbs do not occur on all the nervous trunks of a stump. The arteries, *h i*, frequently take a more or less serpentine course. Their lower ends have become ligamentous as an after result of being plugged (§ 1074). The medullary cavity of the bone is closed by new osseous substance, which sometimes form a bulbous and round or notched swelling. New bone also generally unites the radius and ulna (*h*, Fig. 127, p. 230) of the fore-arm, and the tibia and fibula (*n*) of the leg.

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1078. *Numerical Relations of Nutrition.*—In the healthy human being, the changes undergone by the whole mass are distributed over such long periods of time as to give but very small proportionate numbers for each several day. But since the quantity of food introduced, and of fæces and urine evacuated, cause great fluctuations, the weight of the body will vary in twenty-four hours within the limits thus produced. On weighing myself for many days immediately upon rising, I found that the greatest difference amounted to 16·4 oz. in about 116 lb. 15 oz. of bodily weight. A breakfast may add more than 18 oz.; and a copious micturition may subtract an equal weight.

1079. Confining our attention to the direct evidence of the eye, we find that the food and drink constitute the *ingesta* which raise the weight of the body. While conversely, the fæces, the urine, and the cutaneous desquamation (§ 1015),—together with accidental evacuations of saliva and nasal mucus,—form the *egesta* which diminish its mass. Since the latter substances are in very small quantity, it is usual in these numerical researches to regard only the excrements and urine, including their sum under the name of the "sensible" evacuations.

1080. The carbonic acid given off by the body generally weighs more than the oxygen which is at the same time taken up (§ 846). And not to speak of the subordinate relations of nitrogen, we find that large quantities of watery vapour pass off by the lungs and skin. We have thus a second series of egesta, which, not being directly visible, were named by the older physiologists "insensible" evacuations, and by the moderns "loss by perspiration." Assuming that the weight of the body does not alter, the difference between its ingesta and its sensible evacuations will determine its loss by perspiration.

1081. An examination of the numerical relations of the author's body during three days showed that, on an average, 45,158 grains of food and drink were introduced in the 24 hours. The fæces amounted to 2950, and the urine to 22,363 grains. Supposing the weight of the body completely unchanged, the loss by perspiration was, therefore, 19,846 grains. But a more careful examination proved that 588 grains were retained for the evacuations of the following days. Hence the insensible evacuations amounted to 19,258 grains.

1082. The mode of calculation just mentioned does not presuppose an hypothesis of any kind whatever. The ingesta had to the sensible evacuations the proportion of 45,158 to 25,313, or of 1 to ·56: and to the insensible evacuations, that of 45,158 to 19,258, or of 1 to ·43. About $\frac{1}{100}$th of the food and drink was laid by for the following days. The sensible and insensible evacuations were to each other as 22,363 to 19,258, or as 1 to ·76. Thus 56 per cent of the food was given off in the excrements, and 43 to 44 in the pulmonary and cutaneous evaporation.

1083. But a consideration of that gaseous interchange which accom-

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panies evaporation requires many hazardous assumptions. The oxygen absorbed directly increases the ingesta; but its quantity has never yet been determined by a series of direct experiments. Hence we are obliged to extend the estimates made for a few minutes, and under somewhat constrained breathing (§ 824), over a larger period of time,—a method which greatly multiplies the amount of their errors of observation. A second and equally unsafe method consists in analyzing specimens of the food, drink, urine, and fæces, and subtracting the carbon and hydrogen of the sensible evacuations from that of the food, so as to estimate the remaining carbon and hydrogen as carbonic acid and water. If we then subtract the oxygen contained in the fæces and urine from that of the food, and again deduct this residue from the quantity of oxygen contained in the carbonic acid and the water of combustion, we shall obtain a value which may be regarded as that of the oxygen absorbed. Barral made use of the latter method. But we have already seen (§ 286, § 846) that all this trouble will not afford trustworthy results.

1084. The carbonic acid of evaporation carries off the greater part of the oxygen taken up by the lungs and skin. The surplus may be applied to the oxydation of hydrogen or other bodies.

1085. Let us suppose that the author consumes 520·46 grains of oxygen every hour (§ 824): this will give 12,491 for the 24 hours. The sum of the sensible and insensible ingesta will thus average 57,649 grains. But the sensible evacuations amount to 25,313 grains (§ 1081); so that they claim somewhat less than half. This leaves 32,336 grains for the carbonic acid, the watery vapour, the cutaneous desquamation, and the smaller egesta. But if 14,493 grains of carbonic acid are given off (§ 824), 17,843 (or more accurately 17,235) are required for the watery vapour, the cutaneous desquamation, and the small and casual excretions of saliva, nasal mucus, &c.,—always presupposing that the small quantity of carbonic acid exhaled by the skin is compensated by the somewhat forced respiration which obtains in these experiments.

Reducing everything to parts per cent of the total sensible and insensible evacuations, and adding the results deduced by Barral from his observations, we obtain as follows :—

AVERAGE PERCENTAGE DURING THE TWENTY-FOUR HOURS.

Incomings.		Evacuations.						Residue for the evacuations of the following day.	Observers.
Food and Drink.	Oxygen consumed.	Fæces.	Urine.	Sensible evacuations.	Carbonic Acid exhaled.	Watery vapour.	Cutaneous desquamation and other small losses.		
74·4	.25·6	—	—	34·8	30·2	34·5	·5	—	Barral.
78·3	21·7	5·1	38·8	43·9	25·2	30·		·9	The author.

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Thus the oxygen daily received amounts to $\frac{1}{3}$rd—$\frac{1}{4}$th of the average food and drink. The fæces carry off $\frac{1}{20}$th, the urine $\frac{1}{3}$rd to $\frac{2}{5}$ths, the total of the sensible evacuations more than $\frac{1}{3}$rd to $\frac{2}{5}$ths, the carbonic acid $\frac{1}{4}$th to $\frac{3}{10}$ths, the formation of water about $\frac{1}{3}$rd, and the cutaneous desquamation about $\frac{1}{200}$th, of the whole. On an average, about $\frac{1}{100}$th is reserved for the evacuations of the following day.

1086. If from the experiments made by Barral and myself, we reduce the several ingesta and egesta to fractions of the weight of the body, we find as follows :—(See next page.)

1087. The objections which may be raised against the estimates in Barral's experiments have already (§ 846) been stated. We will therefore limit ourselves to the first two series of these, instituted by this chemist upon his own body. Assuming the food and drink = 100, we have as follows :—

Substances.	Times of Experiment.	Proportionate quantities of the constituents of the ingesta and egesta.				
		Food and Drink.	Fæces.	Urine.	Sensible evacuations.	Perspiration.
Water .	Winter	100	5·3	53·6	58·9	62·4: hence 21·3 water of combustion.
	Summer	100	3·	53·1	56·1	62·: hence 18·1 water of combustion.
Carbon .	Winter	100	4·2	4·1	8·3	91·7
	Summer	100	3·4	5·2	8·6	91·4
Hydrogen	Winter	100	4·2	5·2	9·4	90·6
	Summer	100	3·0	6·5	9·5	90·5
Nitrogen	Winter	100	10·0	38·9	48·9	51·1
	Summer	100	6·1	46·2	52·3	47·7
Oxygen	Winter	100	3·4	3·0	6·4	93·6
	Summer	100	2·9	3·8	6·7	93·3

These numbers confirm many of the facts with which we have been previously made acquainted.

1088. The urine of man carries off more water than the fæces. But in animals whose excrements are very fluid, the reverse is sometimes the case. And persons suffering from violent diarrhœa also lose large quantities of water by the alvine evacuations.

1089. We have seen that, under favourable circumstances, more water is usually carried off by the urine in winter, than in summer. The estimates quoted above exhibit this relation, although not very decisively. The sensible evacuations excrete about as much water as the perspiration, or a little less.

1090. The water of combustion — *i.e.* that portion of water which is not introduced as such, but is produced in the body itself from the oxydation of hydrogen, forms about $\frac{1}{4}$th to $\frac{1}{6}$th of the moisture contained in

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AVERAGE QUANTITY IN TWENTY-FOUR HOURS COMPARED WITH THE WEIGHT OF THE BODY.

Food and Drink.	Oxygen consumed.	Fæces.	Urine.	Sensible evacuations.	Carbonic Acid exhaled.	Watery vapour and cutaneous desquamation.	Perspiration.	Observers.
$\frac{1}{17}$ to $\frac{1}{20}$	$\frac{1}{48}$ to $\frac{1}{61}$	$\frac{1}{338}$ to $\frac{1}{680}$	$\frac{1}{42}$ to $\frac{1}{46}$	$\frac{1}{38}$ to $\frac{1}{43}$	$\frac{1}{39}$ to $\frac{1}{54}$	$\frac{1}{37}$ to $\frac{1}{42}$	$\frac{1}{32}$ to $\frac{1}{37}$	Barral.
$\frac{1}{18}$ — $\frac{1}{19}$	$\frac{1}{67}$	$\frac{1}{347}$ — $\frac{1}{364}$	$\frac{1}{29}$ — $\frac{1}{32}$	$\frac{1}{28}$ — $\frac{1}{46}$	$\frac{1}{58}$	$\frac{1}{47}$	$\frac{1}{32}$ — $\frac{1}{37}$	The author.

These estimates give the following average proportions :—

AVERAGE QUANTITY PER TWENTY-FOUR HOURS FOR EACH POUND OF BODILY WEIGHT.

Food and Drink.	Oxygen consumed.	Fæces.	Urine.	Sensible evacuations.	Carbonic Acid exhaled.	Watery vapour and cutaneous desquamation.	Perspiration.	Observers.
3·78	·133	·014	·154	·168	·164	·182	·203	Barral.
3·78	·105	·021	·189	·210	·126	·168	·168	The author.

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the food. But the experiments on which this estimate is based are such as not to afford very trustworthy results (§ 287).

1091. Somewhat more than $\frac{8}{10}$ths of the carbon, hydrogen, and oxygen of the food reappear in the carbonic acid and water of evaporation. The remainder is pretty equally divided between the fæces and the urine, but the latter generally obtains the greatest share.

1092. We have already (§ 286) seen that such numerical observations include sources of error which prevent them from deciding the more delicate question,—whether any nitrogen, or if so, how much, is given off. According to the mere figures of Barral, an equal quantity of nitrogen is given off in the insensible and sensible evacuations. The fact that the urine contributes largely (§ 954) to the excretion of the nitrogen is also plainly seen in the preceding table (§ 1087).

1093. The food consumed by Barral in the winter series of experiments consisted of meat, potatoes, vegetables, bread, milk, cheese, sugar, wine, and brandy. Calculating the quantities per cent of the elementary substances contained in its volatile constituents, we find 51·06 per cent of carbon, 7·98 hydrogen, 3·9 of nitrogen, and 37·06 of oxygen. The corresponding fæces gave an average of 52·09 of carbon, 7·92 hydrogen, 9·56 nitrogen, and 30·43 of oxygen: while the urine gave 40·9, 8·2, 29·3, and 21·6 respectively. Hence we see that the fæces are chiefly distinguished from the urine by the large quantity of carbon, and small quantity of nitrogen, they contain.

1094. As yet our attention has been limited to numbers which are the averages of a series of observations lasting some days. But there are many collateral circumstances which speedily cause very important variations, and which may thus greatly affect any particular day. It is obvious that a casual constipation will alter the quantity of the fæces, and the copious use of drinks, that of the urine. The quantities of perspiration also rise and fall in visible correspondence with a change of food or bodily activity. They are also capable of being affected by all the causes which increase or diminish the excretion of carbonic acid (§ 808, *et seq.*); so long as these are not compensated by other collateral circumstances. Thus they generally rise during digestion, or continuous bodily movement; and sink during rest, and therefore, during sleep. Finally, the act of sweating is one of the chief causes of variations in these numbers. Fasting and at rest, the author's average hourly quantity of perspiration amounted to 463·3 grains. By walking up hill and down dale, so as to sweat copiously, this quantity was raised to 2048·8; that is, to between four and five times the former amount.

1095. When the egesta of a fasting animal have used up the residue of the food previously consumed, the substances subsequently given off in the fæces, urine, and evaporation must be yielded by the body itself. Hence the weight of the animal continually decreases. An apparent

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exception occurs in the hybernating animals. This was first discovered by Sacc in the marmot; and is confirmed by experiments which I have instituted on the hedgehog. When such an animal is plunged in its deep sleep, its bodily weight increases from day to day until fæces and urine are expelled. But the animal loses more by these evacuations, than it had gained in the preceding period of rest.

1096. The first series of experiments on the numerical relations of fasting were furnished by Chossat, a physician of Geneva. Those subsequently instituted by Schuchardt confirm his principal results.

1097. It is first necessary to distinguish four estimates; viz., the *absolute*, and the *relative*, amounts of the *total*, and the *daily*, loss. An example may illustrate what these numbers mean, and how they may be calculated.

We will suppose that a number of rabbits had been allowed to die of starvation. Each of them weighed 16,874 grains on the first day on which food was withdrawn; and 10,201 grains immediately after death. The difference of these two will give the total absolute loss: or $16{,}874 - 10201 = 6673$ grains. The proportionate total loss is the quotient of the absolute loss divided by the original weight: or $6673 \div 16874 = \cdot 4$, or $\frac{2}{5}$ths. The rabbits die on an average $9\frac{1}{3}$ days after the commencement of fasting. Thus we get $6673 \div 9 \cdot 33 = 715$ grains for the absolute daily loss; and $\cdot 4 \div 9 \cdot 33 = \cdot 043$ for the relative one.

1098. It may be stated generally, that one of the higher vertebrata dies by starvation after losing about $\frac{2}{5}$ths of its bodily weight. As might, however, be expected, the quantities for each case vary within wide limits in different animals and circumstances. But the averages deduced from numerous series of experiments all approximate to ·4 as the proportionate total loss. Thus Chossat obtained from ·31 to ·42 for birds and small mammalia, and ·41 for frogs.

1099. The daily loss varies greatly with the nature of the animal. Confining our attention to rabbits, guinea-pigs, fowls, pigeons, and other domestic birds, the average proportion is ·024—·112; usually ·04. Here from $\frac{1}{2}$ to $2\frac{1}{2}$ weeks suffice to produce death by starvation. But frogs will go for months without any solid food. And hence if they also finally lose $\frac{2}{5}$ths of their weight, their proportionate daily expenditure would be only ·002.

1100. Daily experience teaches us that a fasting animal emaciates; *i.e.*, that its superfluous fat is consumed. But since this cannot cover the nitrogen expended in the urine (§ 948, *et seq.*), other tissues must also be consumed. The weakness of the locomotive organs entitles us to conclude, that the muscles are capable of furnishing an important contribution of this kind.

1101. On comparing the average weights of the several organs in well-fed and starved animals of the same species, we find a great decrease of the adipose tissue and muscles. The bones, the eyes, the

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brain, and the spinal chord, lose least. The great resisting power thus possessed by the nervous centre, is the more remarkable in a chemical point of view, from its containing enormous quantities of fatty matter; mixed, however, with albuminous substances.*

1102. We have (§ 361) seen that being limited to one kind of food finally produces effects resembling those of starvation. Schuchardt attempted to determine the averages for these circumstances by a series of experiments on birds. The results may be compared as follows:—

Accompanying Circumstances.	Relative. Total loss.	Relative. Daily loss.	Duration of life in days.	Average absolute weight at commencement in grains.
Withdrawal of all food	·342	·066	5·28	4478·76
Fed upon groats. All water withdrawn	·439	·04	10·96	4943·6
Fed with 97·5 per cent of watery albumen of eggs, and 2·5 per cent of mineral substances	·335	·046	7·58	5210·8
Fed with 29·5 per cent of starch, 1 of gum, 2 of sugar, 2·5 of oil, 1·3 of mineral substances, and 63·7 of water	·304	·015	21·19	5512·5

We may first remark that the total relative loss of an animal which has perished from the use of an improperly exclusive food, tolerably corresponds to that of an animal starved to death (§ 1097). Death by thirst is less speedy, because solid food always contains certain quantities of water (§ 339). Since the large quantities of carbonic acid in the perspiration—and especially in that of small birds — require much combustible organic matter, it becomes explicable why feeding with hydrates of carbon sustains life almost thrice as long as with albuminous substances. It is obvious that the differences exhibited by the daily relative losses are mere results of the varying durations of life, and the almost equal amount of the total relative loss.

1103. *Chemical Phenomena of Nutrition.*—The blood is the centre of all the functions subservient to the change of substance. It receives many constituents of the food, either directly, or by means of the absorbents (§ 525). The oxygen which it attracts from the atmosphere effects a direct change in many of its constituents. And it is probable that a certain quantity of this gas penetrates the tissues, in order to act, either upon these, or on the fluid by which they are soaked. Since the blood, especially that of the arteries (§ 623, *et seq.*) and capillaries, is exposed to a greater pressure than the nutritional fluid, it will allow the

* Two structural details may also be indicated as affording a partial explanation of this contrast. The vascular relations of fat perhaps place it in peculiarly immediate dependence on the blood. While the cell-form possessed by much of the nervous centre may be conjectured to confer a greater—and in some respects, a more independent—vitality.—EDITOR.

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proper substances to pass through the walls of the vessels. In addition to this, the chemical difference of the neighbouring mixtures will necessarily excite diffusive currents (§ 129, *et seq.*). We have already learnt the important influence exerted by the blood upon the secretions. To it are also due the maintenance and growth of the tissues. Most parts of the body are bathed in the nutritional fluid; and are, as it were, constantly exposed to a permeating stream of this renovating solution. And while the absorbents carry off superfluous water, together with some substances which have become useless (§ 534), the blood permits the transudation of those compounds which are necessary to the restoration or increase of the part.

1104. We will suppose the author takes, on an average, 45,158 grains of food and drink in the 24 hours, and gives off only 2950 grains of fæces. If, in spite of this, the weight of his body remains nearly the same, at least 6lbs. 4¾ ozs. of matter daily enter his blood. But the quantity of blood in his body—which weighs 119lbs.—is about 23lbs. 13 ozs. (§ 694). Hence the fluids daily passing through the blood altogether amount to about ¼th of its weight.

1105. It may probably be assumed that the various kinds of food ordinarily made use of together contain, on an average, 75 to 80 per cent of water, and 20 to 25 per cent of solid residuum. Now since human blood contains, on an average, 78 per cent of water, it follows that the proportionate quantity of transitional substances is somewhat greater for the water, than for the solid residuum.

1106. Water and dilute watery solutions are rapidly carried into the blood (§ 504). Saline solutions, which are in moderate quantity, and not too concentrated, are quickly excreted again in the urine (§ 944, *et seq.*). Substances which are more difficult of solution, and fats, are necessarily delayed some time in the alimentary canal (§ 438, *et seq.*) before becoming the property of the blood. The important but slow changes which most of them suffer will soon occupy our attention. The blood of a person who, from time to time, consumes large meals, must therefore vary greatly. It becomes richer in salts and water shortly after taking much food, and especially after the use of liquids. But the kidneys soon obviate this condition. The other ingesta produce less considerable variations: since they reach the blood in smaller quantities. A part of them undergo important changes in the blood, so as to be at once rendered capable of excretion: while others subsequently follow. This successive play lasts for some time: so that the action of small quantities of these transitional substances is spread over large intervals of time.

1107. Beginning with the consideration of the solid food, we find that the non-azotized kinds—such as the hydrates of carbon (§ 303) and the fats (§ 305)—undergo combustion with the oxygen of the inspired air;

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being converted into carbonic acid and water, so as to cover the carbonic acid given off by evaporation. They have therefore been distinguished by the name of respiratory food. But this term is insufficient; since not only are other compounds subservient to the same purpose, but fats introduced in excess may be deposited as adipose tissue, and may perhaps combine with azotized substances.

1108. It is easy to see why animals fed exclusively on such non-azotized compounds, perish of inanition. Muscular movements, and other functions, use up a certain quantity of nitrogenous substances, the relics of which are removed from the body. The urine always contains urea, uric acid, and other compounds rich in nitrogen; for the loss of which such food furnishes no compensation. Besides this the mixture of the blood necessarily suffers so greatly, as to injure the functions of the most important parts of the body. Hence death is induced, not so much by mere loss of substance, as by an injurious mutual action of the nutritive functions, and by delicate molecular changes of the nervous tissues.

1109. The exclusive use of nitrogenized substances, such as albumen, is equally unsuitable to nutrition. For though it is true that the azotized tissues can thus receive the compensation which their action demands, still, in order that the food should cover the quantities of carbonic acid given off by evaporation, it must enter the blood both quicker and more copiously than the digestive powers will allow. Besides this, the composition of the blood is seriously altered; so that here also the organism is finally undermined.

1110. Hence it is only a suitable mixture of non-azotized and azotized substances which can satisfy the requirements of nutrition. Such a mixture is prepared by Nature in the milk (§ 346), and even in many natural foods (§ 336). Indeed most of the pure azotized or non-azotized substances (in the strict sense of these words) can only be obtained artificially.

1111. The total food of the horse, cow, and hog, contains, according to Boussingault, from 46 to 51 per cent of carbon, and 1·6 to 2·1 per cent of nitrogen. That of the turtle-dove has 47 per cent of carbon, and 3·4 of nitrogen: and that of fowls, according to Sacc, 48 and 2·4 respectively. The ordinary mixed food of the human being furnishes much more carbon than nitrogen: according to Barral, about 51 per cent of carbon, and 3·9 of nitrogen. Since beef contains but 15½ per cent of nitrogen for 53 per cent of carbon, this statement also holds good for carnivorous animals, though in a more limited degree:—a degree which varies with the larger or smaller quantity of fat present.

1112. This fact is the natural consequence of the composition of most organic compounds. Some highly azotized substances—such as urea (§ 321), or allantoin (§ 319)—contain less carbon than nitrogen. But even in uric acid (§ 321), theobromin, thein, and caffein (§ 343), the reverse of this is the case. While the albuminous substances (§ 312),

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and the animal tissues generally (§ 317), contain much less nitrogen; and in vegetables its amount is often very small. And since the egesta of the animal are derived either from its food, its own tissues, or from both of these together, the carbon must greatly exceed the nitrogen in them also (§ 1093).

1113. The preceding estimates (§ 1111) have already taught us how little nitrogen is contained in the food of the large herbivorous animals, such as the horse and cow. And even part of this is lost by passing off undigested in the food. The body of these animals therefore requires but a small quantity of nitrogen. This statement will also apply to some of the carnivora. Dogs may be kept for months upon potatoes and water: the boiled potatoes containing 46·4 per cent of carbon, 6·1 of hydrogen, 1·6 of nitrogen, and 45·6 of oxygen. In like manner these animals live more than half a year when fed upon adipose tissue. Hence the albuminous walls of the fat-cells, and their intervening tissues, contain a quantity of nitrogen (§ 336) which is for a time sufficient.

1114. Many chemists have ascribed too much importance to the azotized constituents of the food. They have arranged the several kinds of food according to their percentage of nitrogen, and have regarded such tables as scales of diet; *i.e.*, as tables, in which the nutritive character of the food rose and fell with the amount of nitrogen present. But there are many arguments which prove that the whole theory is based upon incorrect premises. The study of digestion has already taught us, that the elaboration—and therefore the usefulness—of the food, is not determined by any single constituent, but by its total admixture; and especially by its molecular constitution. Hence the flesh of herrings, with 14·5 per cent of nitrogen, or boiled beef with 15 per cent, or ox liver with 10·7 per cent, are not more nutritious than yolk of egg, which contains only 4·9 per cent. The excess of hydrates of carbon, and especially of starch, which is met with in most parts of plants, greatly diminishes the proportion of nitrogen which they contain. Thus in the different kinds of flour, it is only 1·4 to 2·2 per cent; and in potatoes, turnips, and carrots from 1·5 to 2·4 per cent. The vegetable structures which contain more albuminous substances exhibit a larger quantity of nitrogen. The podded fruits furnish 5 per cent. The fungi are also distinguished by a considerable quantity: from 3·2 to 4·6 per cent. While, in spite of this, they are much less nutritious than many other kinds of animal and vegetable food, which contain, on the whole, much less nitrogen.

1115. Since coffee and tea—two drinks in universal use—both contain a highly azotized alkaloid, caffein or thein (§ 343), it has been thought that instinct has led us to select these two vegetables on account of the large quantity of nitrogen which their alkaloid contains. But no analysis has hitherto shown more than ⅓rd per cent of caffein in the coffee-beans; or ½ to 1 per cent of thein in tea. And even supposing rather more

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than this were contained in the plants themselves, still the infusions in ordinary use could only introduce extremely small quantities of nitrogen into the body. And, on the other hand, the theory that the irritating or poisonous qualities of these alkaloids depend on their nitrogenous constituent, is equally contradicted by facts. The poisonous effect of such alkaloids is not proportionate to the nitrogen they contain. For strychnin, the deadly alkaloid of the nux vomica, contains 5·81 per cent of nitrogen; and the comparatively harmless quinine, 8·1 per cent.

1116. The injurious effect of an exclusively albuminous diet (§ 1109) shows that a mere azotized food does not favour the vital functions, but rather interferes with them. A further consideration of the excretions will hereafter inform us of other facts which lead to the same conclusion. The substances best adapted to the maintenance and growth of the various tissues are mixtures which contain much carbon and a moderate quantity of nitrogen, and which are easily overcome by the organism. The residuum of the milk, which forms the very ideal of a proper food, consists of 57· per cent of carbon, 8·2 of hydrogen, 4·4 of nitrogen, and 30·4 of oxygen.

1117. Many of the hard tissues, such as the bones, can only be maintained by the addition of new mineral substances in the food (§ 1044). But since a fasting animal daily gives off ashy constituents, the quantity and quality of which shows that they could not have been yielded by its skeleton, it follows that the action of its soft tissues excretes a certain quantity of inorganic matters, which require replacement. In point of fact, almost every natural food, whether animal or vegetable, contains certain quantities of ashes, which undergo various destinies in the interior of the body.

1118. Many only enter the blood in very small quantity. By far the larger part of them wanders through the intestinal canal, to be expelled with the fæces. This is especially the case with the silicates, which are largely contained in the stems of plants, and form the basis of their skeletons. Thus the excrements of the horse yield numerous fragments of hay; which retain their previous form, having only undergone mastication and extraction. The urine and the horny tissues, such as the epidermis or hair, contain but very small quantities of silicic acid. When calcareous salts are largely taken in the food, something similar obtains. Thus the fæces of dogs who have eaten many bones are distinguished by the large quantity of lime which they contain.

1119. The more soluble mineral substances chiefly reappear in the urine. The salt so frequently used as a condiment belongs to this class of substances, as long as it undergoes a proper elaboration. But the result depends on the quantity and density of the salts. Small quantities, and dilute solutions, which easily enter the blood (§ 504, *et seq.*), are quickly discharged in the urine (§ 944, *et seq.*). But larger quantities, or

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more concentrated solutions, or—as is the case with the sulphates of soda and of magnesia—a peculiar character of the salt itself, may give rise to diarrhœa :—an action which renders the intestine their chief outlet.

1120. Attempts have often been made to explain the preference accorded to salt as a condiment on chemico-physiological principles. It was supposed that its chlorine furnished the hydrochloric acid necessary to gastric digestion; and its sodium, the soda required for the bile (§ 925). But we have seen (§ 436) that under normal circumstances the acid of the gastric juice is the lactic, and not the hydrochloric. Besides, a large part of it is given off unchanged in the urine. It is therefore probable that the beneficial effects of this condiment depend upon its general characters, and not upon the products of its decomposition. From observations on himself and others, Plouviez believes that the copious use of salt gradually raises the weight of the body to a certain maximum. It is well known that the food of ruminants is often mixed with salt to facilitate fattening. The experiments instituted by Boussingault on bullocks showed that their activity was thus increased, although their bodily weight was not raised to the extent anticipated.

1121. It is probable that the phosphates and sulphates of the alkalis also exert an important influence upon nutrition. We have (§ 965) seen that their quantity is larger in the urine of the carnivora. The metamorphosis, restoration, and growth, of the nitrogenous tissues are probably connected with a cycle of these substances. Besides this, a solution of an alkaline phosphate is capable, both of taking up carbonic acid with great facility, and of disengaging that previously combined with it under the influence of collateral circumstances. Hence many have believed that this process obtains in the living blood.

1122. The poisonous or injurious effect produced by the ingestion of many substances is only relative. Too large a quantity of nutritious food is capable of gradually destroying the body. On the other hand, some poisons which rapidly kill one class of animals, leave another unhurt; or lose their injurious effects when united with particular substances, or introduced into the body by particular channels. Horses bear much larger quantities of prussic acid than man and most of the smaller mammalia. According to Fontana, snakes, tortoises, snails, and leeches, are not killed by the poison of vipers. Although arsenic is one of the most violent and insidious of poisons, yet, according to Berthold and Bunsen, rabbits sustain a solution of kakodylic acid with impunity. Many creatures eat wourali poison in tolerably large quantities without injury; while its introduction into the blood kills most animals in a short time. The same holds good of some other poisons prepared by the natives of the American forests.

1123. That absorption of oxygen and expulsion of carbonic acid which accompany the respiration of the higher animals produce a remarkable

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change in the blood (§ 724, *et seq.*). Since the smaller branches of the pulmonary veins and systemic arteries convey a bright-red blood, and those of the pulmonary arteries and systemic veins a dark red fluid, it follows that at least the greater part of the change of colour occurs in the capillaries. In the fine vascular network of the lungs the blood loses part of its carbonic acid, and receives the oxygen inspired. In the systemic capillaries this change is reversed. But in all probability a twofold process occurs here. It is possible that a part of the substances directly taken into the blood from the alimentary canal undergoes an immediate combustion, and thus furnishes carbonic acid at the expense of a certain quantity of the oxygen consumed. We may conjecture that the darker colour of the portal blood (§ 921) noticed by some observers is due to this cause. And the action of the organs destroys certain constituents of their substance. The effete compounds thus produced probably contain carbonic acid, or will at least produce it whenever they acquire a certain quantity of oxygen. Hence there will be a mutual exchange between the nutritional fluid and the blood at all points of their mediate contact, and especially at the vast surface presented (§ 689) by the capillaries.

1124. It is obvious that the admixture of the blood will vary with the circumstances of the individual, and with the existing state of absorption and excretion. This increases the difficulties of all inquiries instituted upon this topic. Besides this, chemistry has hitherto failed to discover any method of analysis which gives a satisfactory account of the intimate composition of the blood. For these reasons, the numerous researches instituted on the human blood in health and disease offer a confused mass of results, containing but few trustworthy facts.

1125. According to the averages of Becquerel and Rodier, the blood of the adult male contains 77·9 per cent of water, and 22·1 of solid residuum. The latter consists of 14·1 parts of blood-corpuscles, 6·9 albumen, ·2 fibrine, ·2 fat, and ·7 of extractive matters and salts. Hence we see that the fibrine, which apparently enters so largely into the coagulated blood (§ 1005), constitutes in reality but a small quantity of its mass. In the clot, it mechanically encloses large quantities of serum and blood-corpuscles (§ 1001).

1126. The blood of the female contains, on an average, more water, and fewer corpuscles. According to Denis, that of the new-born infant has a greater density than that of the female at the end of pregnancy.

1127. When blood is repeatedly taken from the vein of an animal, the amount of its water rises after much has been lost. This change may even be produced in a few minutes, by the removal of very large quantities. It is probable that the elasticity of the walls of the vessels, and especially of the arteries (§ 57), prevents these tubes from collapsing beyond a certain limit. We may conjecture that after the loss of a

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large quantity of blood, this fluid attracts watery solutions from wherever it can; from the absorbents, or the nutritional fluid. Its increased quantity of water may thus be explained.

1128. The question, in what cases the fibrine really increases or diminishes, is met by insuperable difficulties. The presence of many substances prevents coagulation (§ 1004). It will therefore first depend upon the composition of the blood, how much of this substance is set free. As Virchow has accurately observed, many fluids only deposit their coagulable contents after long exposure to the air. So that there are supplementary causes, which lead to the formation of what are called fibrinous substances. In addition to this fact, these substances have such indefinite chemical characters, and their boundary from the albuminous compounds is so indistinct, that all basis for further conclusions is wanting.

1129. The blood-corpuscles sometimes exhibit more favourable circumstances. Numerous observations teach that, in women suffering from chlorosis, their number is diminished, and that it is increased by the use of medicines containing iron. And since the greater part of the colouring matter of the blood is connected with its corpuscles (§ 1002), the muddy yellow or pale green colour of the face in chlorotic girls is easily explained. According to Hannover, the subjects of this disease exhale more carbonic acid than healthy women. Hence the number of blood-corpuscles does not directly measure the quantity of respiratory products.

1130. In some cases, the blood or its serum (§ 1001) exhibits what is called a milky character. The blood of sucking animals is sometimes mixed with white streaks. In man, a white or yellowish-white serum is rarely deposited after coagulation. This often depends upon a real excess of fat: but too large a quantity of colourless corpuscles may produce a deceptive appearance of the same kind.

1131. There are many phenomena which indicate, that substances only present in the blood in very small quantity nevertheless exert an important influence on the vital functions. Such are the transfusion of heterogeneous kinds of blood, the ordinary changes of nutrition, and the influence of certain poisonous compounds. Hence it is probable that, however completely the blood may hereafter be analyzed, many important questions will only be decided by examining several pounds of this mixed fluid.

1132. Transfusion consists in injecting the fluid blood of one animal into the vessels of another. This operation has frequently been performed on the human subject after considerable losses of blood, such as uterine hemorrhages. In order to diminish the danger of obstruction by coagulation, the blood injected is generally deprived of its fibrine.

1133. It frequently happens that an animal dies shortly after the

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injection (Tab. II. Fig. 23, *a*) of the blood of another species. Although frogs possess blood-corpuscles which are much larger than those of man and mammalia (Tab. II. Fig. 24, *a d*), still they cannot bear the transfusion of human blood. Hence death does not depend upon a mechanical obstruction of the smaller vessels, but upon more recondite causes. A fact communicated by Bischoff leads to the same conclusion. He found that mammals died after the injection of the venous blood of birds, but not after that of the arterial fluid.

1134. We have already seen (§ 1106) that the less soluble parts of the food only enter the blood slowly, and in small quantities. This circumstance explains many processes of the ordinary interchange of matter.

1135. The starch of the food is gradually converted into grape-sugar (§ 461) or lactic acid. Hence the small quantities taken up by the blood, at short intervals of time, are thus enabled to undergo complete combustion into carbonic acid and water. We therefore find no sugar in the urine. On the other hand, after much sugar has been consumed, the blood receives more of this soluble substance than it can at once elaborate: so that part of it re-appears as such in the urine.

1136. The slow alteration and absorption of fatty matters in the small intestine (§ 480) probably leads to a similar result: that, namely, of preventing the blood from being overladen with these substances. This explains why Boussingault[37]) was unable to detect any constant difference in the fatty contents of the blood of ducks and pigeons, whether fed upon starch or albumen, or not fed at all.

1137. The phenomena which attend the metamorphosis of albuminous bodies point to the same conclusion. The ingestion of these substances has a remarkable effect in increasing the quantity of urea in the urine (§ 951). But, since the blood only contains traces of this substance (§ 957), it follows, that the large amount given off is gradually accumulated by a continual and repeated secretion and excretion of very small quantities. And the albuminous urine sometimes passed by weakly subjects shortly after a meal may depend on the fact, that the lax porous walls of their vessels do not afford the necessary protection (§ 144). It would thus constitute a phenomenon like that which follows the ingestion of large quantities of sugar.

1138. The phenomena of infection show what an influence may be exerted by minute quantities of matter. The drop of lymph introduced into the vaccinated arm forms a quantity which is inconceivably small in comparison with that of the blood. And since it contains but little solid residuum, the quantity of its active constituents is yet smaller. Still the action of these continues for a whole week, until the pustule of inoculation is completed, and the protective substance is reproduced in the vaccinated person. And this process, which is only paralleled by some contactive effects (§ 299), leaves behind it a

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permanent change. For after successful vaccination, the susceptibility for true small-pox disappears; either for ever, or, at any rate, for a number of years.

1139. The evacuations of an animal which has fasted for a long time, and has consumed most of the relics of food that remain in its intestine, are less than usual. Its fæces and urine are diminished, as well as its absolute quantity of urea : it exhales less carbonic acid, and consumes less oxygen, than a healthy animal. But up to the last moment of life, none of these evacuations are totally suppressed.

1140. The emaciation of the fasting animal shows that these evacuations come from the decomposition of its tissues. Since a mammal whose blood amounts to about $\frac{1}{8}$th of its weight (§ 694) loses $\frac{2}{8}$ths before it dies of starvation, it follows that the matters gradually given off in its evacuations together make up an amount which exceeds that of the blood. But the loss of substance is chiefly caused by the various functions. The muscular contraction necessary to the action of the heart (§ 575), to the respiration (§ 739), to the local transference of the secretions (§ 867), and to the voluntary or involuntary phenomena of movement, furnishes a series of substances undergoing metamorphosis, which are finally given off as carbonic acid, water, urea, &c. Violent exertion of the fasting animal increases its evacuations. While conversely, in the hybernating animal they sink to very small quantities. But since a torpid hedgehog, which remains for days in the same place, with scarcely any respiration, and a slow and infrequent cardiac beat, still voids both fæces and urine (§ 1095), it follows that these sensible evacuations do not necessarily depend upon the ingestion of food. The metamorphoses of the different tissues furnish a certain quantity of water and organic matter, which can only be got rid of in this manner.

1141. The continuance of the heart's pulsations and of the respiratory movements, together with the final appearance of febrile phenomena, would lead us, *à priori*, to expect, that the starving animal gives off large quantities of carbonic acid. Boussingault found in his quantitative researches that the carbon and hydrogen given off by fasting pigeons was from $\frac{1}{2}$ to $\frac{1}{3}$rd of that furnished by well-fed birds of the same species. But Regnault and Reiset did not observe such a difference. Comparing their averages we obtain the following numbers :—

Animal.	Average Quantity of Carbonic Acid in grains, for each pound of bodily weight.		Animal.	Average Quantity, in grains, of Carbonic Acid, for each pound of bodily weight.	
	Fed.	Fasting.		Fed.	Fasting.
Rabbit . .	8·19	4·97	Fowl . . .	9·73	6·58
Dog . . .	9·17	6·3	Duck . . .	12·32	9·24

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These observers state that the fasting animal takes up rather more oxygen than it gives off of carbonic acid. In fasting rabbits, the proportion of the latter (§ 840) amounted to ·93 to ·97; in dogs, ·996; in the fowl, ·88 to ·97; and in the duck, ·95. Supposing this was not caused by the mode of respiration (§ 814), it would follow, that in the fasting animals, more of the oxygen consumed is applied to the combustion of hydrogen, or to the production of those organic compounds which are given off in the sensible evacuations. In two marmots, the proportion of carbonic acid in the waking state was 1·17: while in one partially asleep it was ·55. This difference must be still more strongly marked in the state of complete torpidity.

1142. Since the fasting animal consumes its own body, it behaves to some extent like one of the carnivora, even although itself belonging to the herbivora. This fact explains the acid character of the urine passed by the fasting rabbit (§ 972), and the larger quantity of phosphates and sulphates which occur in that of the fasting human being.

1143. Hitherto those metamorphoses of the tissues which accompany the various functions have not received a successful chemical investigation. We can only deduce a few general statements from those of the collateral circumstances with which we are best acquainted.

1144. The substances which are produced by the contraction of muscle, and which are immediately transferred to the nutritional fluid, undergo a second change in the blood, before leaving the body by the urine. Urea is found in the blood, but not in the watery extract of muscle. And the absence of lactic acid from the fresh urine would, if true, indicate the same fact; since it is present in muscle. At present, it is doubtful whether kreatin is produced by the chemical decomposition of the urine (§ 961); and hence its relations are as yet uncertain. We are equally in doubt whether the oxygen of the blood does or does not produce an increased quantity of sulphates and phosphates from the sulphur and phosphorus of the metamorphosed albuminous substances.

1145. We have (§ 958) seen that the artificial oxidation of uric acid produces carbonic acid, urea, and other supplementary compounds. The ingestion of urates also increases the quantity of urea contained in the urine. It may therefore be conjectured that the urea secreted under ordinary circumstances is due to oxidized uric acid. Small quantities of this acid remain unchanged, and reappear as such in the urine. But the hippuric acid (§ 321) is a complementary product of decomposition; and contains more carbon and less nitrogen.

1146. The chalky deposits which stiffen the joints of gouty subjects consist chiefly of urates, and principally of the insoluble urate of soda (§ 977). Hence this disease has been attributed to what is called the uric acid diathesis:—*i.e.* to a deficient oxidation of the uric acid originally produced.

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1147. Since part of the bile is absorbed in the intestine (§ 468), Liebig has assumed that the compounds thus returned into the blood are subservient to respiration. The accompanying organic products would be given off in the urine. But considering how little bile is secreted by the liver (§ 917), it is evident that all the carbonic acid given off cannot come from the absorbed biliary substances. Still it is possible that the constituents of the bile, which is itself a deposit purifying the blood, tend to undergo a final decomposition. Under the influence of alkalies, the cholic (§ 926) and hippuric acids furnish glycose: the former also producing cholalic, and the latter benzoic, acid.

1148. From observations on dogs and rabbits, Frerichs [38]) supposes that the urine of an animal which is fed on non-azotized food contains about as much urea as that of a fasting animal. And conversely, we have already seen (§ 951) that the use of highly azotized food greatly increases the quantity of urea. The differences in the urine of herbivorous and carnivorous animals (§ 972) are explained by the different products of metamorphosis derived from the ternary or quaternary (§ 269) compounds of which their respective food chiefly consists.

1149. The cycle undergone by the highly azotized parts of the food has been explained in two ways. Many imagine them to be decomposed in the blood. According to this view, the constituents of the food undergo a simple transit, which only protects the tissues from the assaults they sustain during fasting. Others, on the contrary, suppose that the highly azotized compounds of the ingesta are converted into the elements of the tissues; and that these give off corresponding equivalents of decomposed substances. But this theory involves two results which are not supported by the other vital phenomena. The several tissues would thus undergo a very rapid integral renovation; and the carnivora would be subject to a far more rapid change of substance than the herbivora.

1150. A third hypothesis has more probability than either. According to it part of the highly azotized food taken up by the blood is decomposed, in this fluid, into carbonic acid, uric acid, and other compounds, which are given off in the different evacuations. But since this metamorphosis is limited by the composition of the blood itself, another part exsudes into the nutritional fluid. Here it compensates what is necessary; and, with the metamorphosed substances furnished by the wear and tear of the functions, returns into the absorbents, perhaps also into the veins. Subsequently it also is decomposed, and appears in an altered form in the evacuations. This view does not assume any simple passage of the food through the blood. And it has the additional advantage of not presupposing any wide contrast between the change of substance in carnivora and herbivora.

1151. Starchy substances are frequently converted into grape-sugar

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or lactic acid (§ 461). But they often assist in the production of fat: perhaps by means of a fatty fermentation (§ 326). The well-known effect of cramming geese may be thus explained. Connected with this is the fact, that a milch cow gives off more fat in her milk than she has taken in her food.

1152. Although the combustion of the hydrates of carbon, like that of the fats, may furnish large quantities of carbonic acid, still it is by no means indifferent which of these two non-azotized classes forms the food. The fats (§ 305) require more oxygen for this purpose than the starchy substances (§ 304). This explains why a dog fed upon beef fat gradually becomes fat but not strong, and constantly gives off an exhalation which has a repulsive odour of the volatile fatty acids (§ 309). In addition to this, it is obvious that the differences in the combustion of the hydrates of carbon and the fats will react upon the excretions generally.

1153. Many ashy constituents of the food immediately enter the urine. Others undergo a previous oxidation at the expense of the oxygen of the blood (§ 973). Since the muscles contain more potash and magnesia, and the bile and blood more soda and lime (§§ 354 and 925), it is probable that there is some approach to a separation in this respect. Under ordinary circumstances, human fæces contain more magnesia than lime.

1154. The metamorphosis of the tissues is even more obscure than that of the food. As yet chemistry is unable to investigate the minute differences of the several constituents; or even the essential characters of the various compounds of albumen, fibrine, and cartilage. Many of the expressions made use of in this subject are base upon insufficient evidence. For instance, when we speak of a fibrine of the muscles, this name is founded upon an assumed resemblance to the fibrine of the blood. But microscopic observation contradicts this parallel (Tab. IV. Fig. 64, and Tab. II. Fig. 25, *a*). The albuminous substances, which are probably of at least two kinds, are easily converted into each other, as well as into other organic compounds. These slow and complicated changes,—which, though successfully accomplished by Nature, remain unnoticed by the comparatively coarse tests of the chemist,—lead to important differences both in external appearance, and in physical properties.

1155. The few facts hitherto established relate to the gradual changes undergone by the tissues in the course of their development. When young structures rich in albumen subsequently become horny, they lose in carbon, and hence gain in nitrogen. The frequent deposit of fat and pigment in and between the horny tissues is probably connected with this fact (§ 1030). Mucus is produced as an alkaline or saline solution of compounds which belong to the group of horny substances constituted by keratin and its congeners (§ 880, *et seq.*). Permanent cartilage furnishes chondrine; but the cartilage of bone, gelatine (§ 317).

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The bones of children, or of morbidly ossified new structures, contain a smaller proportion of calcareous salts.

1156. The true dental substance (Tab. III. Fig. 49, *a d b*) contains 71 to 79 per cent of ash; while the enamel (Fig. 49, *b c*) has from 94 to 96·4 per cent. The teeth as a whole contain 78·8 per cent. In man and the mammalia, healthy bone contains one third of organic cartilaginous skeleton, and two thirds of ash. Carbonate and phosphate of lime form the bulk of the fixed compounds: of these the carbonates are the smallest fraction. Mollities ossium, scrofula, and sometimes caries, are associated with a diminution of the earthy salts, and an increase of the organic compounds. The abnormal flexibility met with in the first two forms of disease is thus explained. Here the acid urine sometimes contains larger quantities of calcareous salts.

1157. None of the natural soft tissues contain such large quantities of ash as those which we have just been considering. The cartilages, which have the next greatest share, only yield $\frac{1}{20}$th to $\frac{1}{25}$th of the quantity possessed by an equal weight of bone. The other tissues have still less. The fixed constituents are generally greater in old age than in the earlier years of life.

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CHAPTER XIV.

ANIMAL HEAT.

1158. A mammal or bird which is surrounded by an atmosphere at 50° to 68° has a temperature of about 99·5° in its mouth, rectum, or other internal parts. This difference of temperature is called animal heat; and the creatures which exhibit it are called warm-blooded animals. And since the temperature of most amphibia, fishes, and invertebrata differs but little from that of their surrounding medium, they are called cold-blooded animals.

1159. But these two classes of the animal world cannot be sharply defined. Many reptiles (such as the oviparous snakes), certain fishes (such as the tunny), and many gregarious insects, exhibit an elevation of temperature which, though never reaching that of the warm-blooded creatures, is still very considerable. The heat found in the interior of bee-hives chiefly depends on this cause. The hybernating animals, in their winter sleep (§ 1095), behave like cold-blooded creatures; while, in the waking state, they correspond with other mammalia.

1160. A more careful examination into the circumstances of what are called cold-blooded animals shows that they are by no means devoid of all independent heat. But the quantities which they evolve are so small as to be mostly either compensated, or overcome, by any active cause of cooling. Hence in the most favorable instances their temperature is but little raised; while in the least favorable, it is positively lowered. Since their heat is more altered by collateral causes, and is hence more variable to the eye, Donders and Bergmann propose to call them *poekilothermal*, or of variable temperature; and the warm-blooded animals *homothermal*, or of uniform temperature.

1161. The animal heat has been determined in two ways: by the thermometer, and by the thermo-electric apparatus. The latter verifies fractions of degrees which surpass the powers of the most delicate thermometer.

1162. The annexed wood-cut (Fig. 185) represents a form of thermometer suitable to such observations. The bulb, *a*, and lower part of the tube, *b*, project out of the case, *c*, in which they are inserted at *d*. Thus *a* and *b* may be introduced into the external auditory meatus, the rectum, or the vagina of small animals. The bulb being bare, the quicksilver rises more quickly to the requisite height. And the rapidity with which

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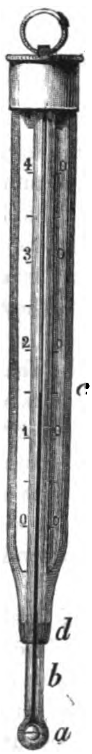
it rises is increased by the fact, that the diameter of the tube, *b*, forms but a small fraction of that of the bulb, *a*. The division need only be 115°; since the temperature of animals is never higher.

FIG. 185.



1163. Two or more rods of a different metal, soldered together, and forming part of a closed circuit, furnish an electric current which may be recognized by the galvanometer (§ 220), so long as the temperature of the one point of union differs from that of another. Bismuth and antimony are best adapted for such observations. Copper and iron produce less decided effects upon the magnetic needle. The deviation of the latter increases with the difference in temperature of the points of junction. Hence this, with the warmth of one junction, will inform us of the temperature of the other.

1164. These brief allusions may explain the thermo-electric apparatus used in physiological researches. The apparatus made use of by Becquerel and Breschet is represented in Fig. 186. The two copper needles, *a* and *b*, are connected at *c* with a galvanometric apparatus, called a thermo-multiplier. A steel needle, *e f*, is soldered to a copper one, *d e*: the former is united with the end of the steel wire, *g*, and the latter with that of the copper wire, *a*. A second piece, *h i*, also consists of a copper wire, soldered to a steel one. Supposing everything else removed, and *h i* united with *g* and *b*, *a d e f g h i b*, and the wire of the thermo-multiplier *c*, form a closed circuit. Hence when the point of junction, *e*, becomes warmer or colder than that belonging to *h i*, the magnetic needle at *c* will deviate to a certain amount.

We now plunge *d e f* into a receiver filled with water, *l*, the temperature of which is shown by the thermometer, *m*. This receiver is placed within a second one, *n*, the temperature of which is notified by the thermometer, *o*; and which can receive a stream of warm water from *p*, through *s t u*, and allow the surplus to flow off from *w* towards *x*. This arrangement maintains a constant temperature of the water in *l*, and hence of the junction, *e*. If the other soldered needle be passed through the muscles, *k*, of the human forearm, the magnetic needle at *c* will deviate by a certain arc of the graduated circle. Supposing that the amount of this deviation corresponds to 3·06 of Fahrenheit's scale, and that the thermometer, *m*, stands at 95°, the temperature of the muscle must be 98·06°.

1165. In the human subject, the thermometer averages 98·6 to 99·1 under the tongue, 98·6 to 102·2 in the rectum, 100·2 to 100·9 in the vagina, and 97 to 101·5 in the urethra. While Breschet and Becquerel

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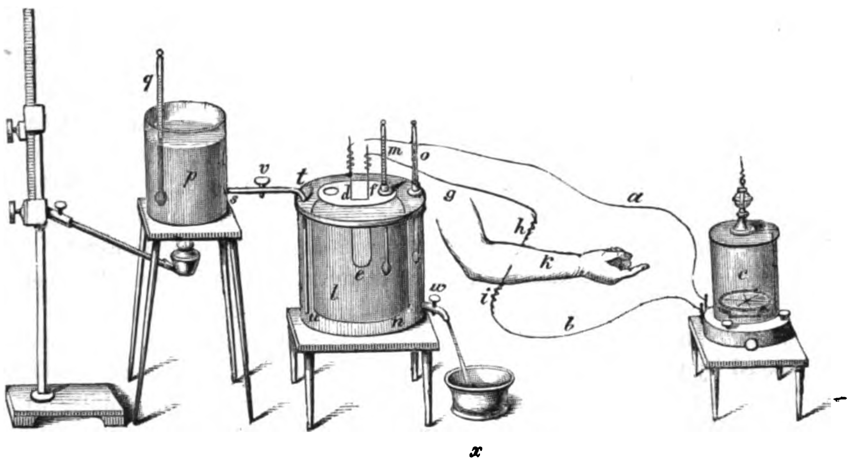
found only 94·6 for the subcutaneous areolar tissue, and from 98·1 to 98·6 for the biceps muscle of the upper arm. The external skin, which is cooled down by the atmosphere and other bodies in contact with it, gave almost everywhere still lower temperatures. Under ordinary circumstances it is between 89·6 and 97·7.

FIG. 186.



1166. Many of the deeper internal parts of mammalia (and probably of men also) are warmer than the structures just mentioned. For instance, Berger found 104·5 for the brain, 106·3 for the liver, and 106·5 for the lungs, of the sheep. Most observers have found a somewhat lower temperature in the venous than in the arterial blood. Breschet and Becquerel state that the blood of the aorta and femoral artery is from 1·4 to 2· warmer than that of the vena cava. But Hering obtained contrary results. The venous blood of the right ventricle of the calf with ectopia already mentioned (in § 633), gave 102·9; while the arterial blood of the left ventricle was but 101·8. Berger has found a similar difference in the sheep.

The amount of animal heat may be greatly altered by a number of collateral causes, which will shortly be again adverted to. But its variations are generally within narrow limits. The differences often amount but to fractions of degrees; and are rarely more than from 1·8° to 3·6°. This fact renders it very difficult to investigate the more delicate effects of external circumstances. We are constantly referred to numerical averages, which are rendered unsafe by the numerous, though tolerably uniform, causes of excitement which exist.

1167. Differences of age and race, or of elevation and climate, lead to no constant differences of animal heat, such as exceed the ordinary variations just mentioned. An old man of 80 or 90 exhibits a

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temperature of 98·6° to 99·5°; just like the child only born yesterday. According to J. Davy, the sublingual region gave on an average 99·1° for the English inhabitants of Ceylon, and from 98·6 to 101·5 for the numerous coloured races of this island. It has often been asserted that the dark skin of the negroes is adapted to the hot climate to which they originally belong. But although there are numerous physical reasons which militate against this view—as well as the fact that brown and red races inhabit the colder zones—still it is remarkable, that the highest temperature of 101·5° was exhibited by albinos of negro race.

1168. Breschet and Becquerel found that the heat of the same young man's biceps amounted to 98·32 at Martinach in Wallis, and 98·51 on the St. Bernard: the former place being 1562, and the latter 7195, feet above the level of the sea. The observations of Eydoux and Souleyet lead them to conclude, that the average animal heat at Cape Horn, at 32° of temperature, and 59° of south latitude, is only 1·8° less than usual.

1169. This slight alteration in the temperature of internal parts is repeated under many ordinary circumstances. When a person is in a warm bath the heat of the skin is certainly increased, since it is less cooled by the outer air, and by the evaporation of water from the blood. Internal surfaces, like that of the urethra, exhibit something similar to this. While on the other hand, in Breschet and Becquerel's researches, the temperature of the biceps only rose ·72°, when that of the surrounding water amounted to 120·2°. And even when the arm is kept some time in freezing water, the heat of this muscle scarcely falls ·36°.

1170. From reasons which may easily be conceived, an animal into whose blood a large quantity of cold water has been injected, at first offers a somewhat lower temperature. According to Bergmann, a similar depression of temperature obtains in the sublingual region of persons who have been taking cold fluids. And conversely, the act of digestion, or rather the more energetic phenomena of combustion which it produces (§ 822), increase its amount. Thus Gierse found that the temperature beneath his tongue was 98·78 before, and 99·5 after, an early dinner. The contraction of the muscles raises their animal heat. Breschet and Becquerel obtained an increase of 1·8° in the biceps. Davy found that continuous movement increased the temperature of the skin, the mouth, and the urine. Hence the more active metamorphosis of the tissues which then occurs reacts as much as possible upon the rest of the organism. The combustion and levelling of temperature (§ 197) thus induced in many parts (§ 330), also contribute to this effect.

1171. The thermo-magnetic researches instituted upon frogs by Helmholtz showed that the temperature of the contracting muscles is raised much more than that of the nerves which excite the contractions. On throwing the femoral muscles of a prepared frog into continuous tetanic convulsions by means of electrical irritation of the spinal chord, the heat

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of the muscular substance rose from ·25° to ·32°; while that of the nerves was either not increased at all, or at most but from ·0036 to ·0054.

1172. An animal dying of starvation may exhibit greater or less amounts, under different circumstances. But, according to Chossat, the averages experience a gradual increase. The only considerable exceptions to this rule occur in the periods of time just before death.

1173. Fricke and Gierse could not detect any constant elevation of temperature in the vagina (*z* Fig. 9. p. 34.) of pregnant females. Nor does menstruation cause any important deviations: the vagina then having the ordinary temperature; or, at most, but ·54° more.

1174. According to Breschet and Becquerel, when the skin of a rabbit is covered with an air-tight varnish, the temperature of the dying animal sinks in an extraordinary degree. The muscles formerly at 100·4° sink in one hour to a temperature of from 68·4 to 76·1°.

1175. During the hot stage of a febrile attack, the temperature of the skin is but little increased. But here, as in many other cases, we must distinguish between the objective heat shown by the apparatus (§ 1162), and the subjective feeling of warmth. The former is the necessary result of the chemical actions of the organism, and of the collateral causes which operate in conjunction with it. The latter, on the other hand, merely expresses certain molecular changes of the nervous substance; which will occur under very different circumstances, and may be indicated in a great variety of ways. The peculiar phenomena seen in intermittent fevers evidently support this view.

1176. It might be expected that a man attacked by the violent shivering fit which commences an intermittent fever, would exhibit a diminished heat of skin. But the thermometer shows that exactly the opposite is the case—that the temperature is higher than usual: and, according to Gavarret, the difference may amount to 7·2°. The subjective character of this sensation of cold explains why the shivering does not disappear immediately on covering up the patient. The heat which subsequently occurs is, for the same reason, not accompanied by an elevation of temperature, although the patient thinks himself almost on fire. The feeling of the hand may also greatly deceive us. For although the sense of touch possessed by our fingers seems to inform us that the skin is greatly heated, still a physical examination shows that the difference is much less than might be supposed. Finally, the sweat which concludes the whole will rather lower the temperature of the skin, by that evaporation of fluid (§ 184) which it implies.

1177. We have already seen (§ 209) that the animal heat is chiefly based upon that process of combustion which is continually going on in the organism. The limited elementary analysis (§ 330) induced by the oxygen inspired,—together with the metamorphosis of certain quantities of carbon and hydrogen contained in the food, and in the several parts of the

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body,—must set free a definite number of units of heat (§ 208). These will first warm those structures of the body in which this process either occurs to a very small extent, or not at all (§ 202). They will also replace the losses of temperature caused by the surrounding atmosphere, by the ground beneath the feet, or by the introduction of cold food. Hence the metamorphosis of its substance constitutes the body a kind of oven, which heats both itself and the neighbouring substances; and, in the warm-blooded animals, maintains itself at as constant a temperature as possible.

1178. This uniformity of the animal heat is not so mysterious a phenomenon as it might seem at first sight. We may often see that the chief causes of the change of substance, the necessary quantities of food, the consumption of oxygen, the formation of carbonic acid, and the general process of combustion,—all vary greatly with those collateral circumstances which are connected with the development of heat.

1179. Other circumstances being equal, a small body cools more quickly than a large one, because it exposes a greater amount of surface* in proportion to its bulk to that surrounding medium by which its surplus heat is carried off. Hence in order that its temperature should remain constant, it ought to possess a more active source of heat. This rule holds good for the smaller warm-blooded animals, as far as circumstances will permit.

1180. The quantities of oxygen consumed (and to some extent those of carbonic acid given off) afford a tolerable, though by no means perfect, measure of the amount of heat set free by that process of combustion which takes place in the body. And since a greater expenditure demands a greater income, a small animal will, as a rule, eat proportionally more than a large one; will take up more oxygen, and will exhale more carbonic acid.

If we collect a few of the averages relating to this fact, we shall find that, on the whole, they confirm this proposition. For instance,

Animal.	Average volume of the body in cubic inches.	Average number of grains per hour, for each pound of bodily weight.		
		Food.	Oxygen consumed.	Carbonic Acid exhaled.
Man	3112·43	15·82	4·34	5·04
Old Dogs	353·35	—	8·33	8·82
Very fat Puppies	46·08	—	7·35	7·7
Old Rabbits	205·66	—	5·95	7·21
Young Rabbits	12·27	—	8·82	10·08
Mice	·604	114·8	76·09	86·31
Pigeons	19·35	—	9·17	10·78
Crossbills	1·65	—	76·79	84·21

* See § 869 and foot note.

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Hence the mouse consumes a proportion of food about eight times larger than that of man. And as it takes much less fluid than we do, the relative quantity of solid matter is still greater. This constitutes one of the chief causes why it takes up from 17 to 18 times as much oxygen, and also gives off larger quantities of carbonic acid. The numbers adduced for the crossbills also teach us, that smaller animals develope more heat. And the other animals mentioned confirm this conclusion, though with less strikingly contrasted figures.

On examining more carefully into the several numbers, we first of all find, that the quantities of oxygen consumed do not increase in inverse proportion to the volume of the body. Thus, although man is about ten times as bulky as a dog of average size, his relative consumption of oxygen is only one-half of that animal's.

We further observe, that birds by no means possess the advantage over the mammalia which is usually ascribed to them in this respect. For instance, on examining into the temperature of the cloaca of birds—*i.e.* of the outlet common to the urinary, sexual, and alimentary canal—we generally find it about 105·8° to 109·4°, or something more than in mammalia. Very small birds, which fly here and there incessantly, certainly consume a comparatively large quantity of oxygen. But the mouse, which is still smaller, exhibits a more active combustion than the larger singing birds. And in the middling sized domestic birds, such as fowls and pigeons, the heat of the body scarce exceeds that of a young rabbit.

1181. It is obvious that a variety of circumstances will exert an important influence in this respect. Such are the peculiarities of the animal's tissues, the nature of its food, the mechanism of its respiration, the amount of watery vapour it gives off, and the process of cooling to which it is exposed. It is to these causes that we must attribute the fact, that very fat puppies give off proportionally less carbonic acid than older animals.

1182. A man breathing in the cold takes into his lungs a denser air (§ 195). Hence, even though the volumes remain the same, he consumes a greater weight of oxygen. He can therefore effect the combustion of a larger quantity of food, and can heat his body to a greater degree. Thus the more active cooling process which accompanies the cold of winter finds its compensation in the heightened function of respiration. This also explains why remaining in the cold excites hunger, and why the appetite is so remarkably diminished by exposure to great heat.

1183. But however strongly the facts just adduced support the view, that the animal heat results from that process of combustion which occurs in the body, still we are quite unable to follow out this theory in a satisfactory manner, or to define the influence which is exerted upon it by other collateral causes. It has frequently been attempted to calcula

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the combustive heat of the animal body by the method previously mentioned (§ 209),—comparing the amounts of heat thus set free with those lost by the causes of cooling. In this way round numbers have been obtained, which seem to explain the independent temperature of the animal body, and even the slowness with which cooling takes place in the interior of the dead subject. But nothing can be proved by these calculations, because they are based upon a series of assumptions many of which are at least improbable, if not incorrect. We do not know what organic substances undergo combustion in each particular instance; and therefore we cannot decide how many units of temperature are set free (§ 208 *et seq.*). Besides, all the estimates, both for heating and cooling, are only averages: which certainly deserve an inspection, but cannot be regarded as proved.

1184. And even apart from this, we meet with many other phenomena, which the theory of combustion cannot at present explain. Many of the effects produced by the nervous system,—such as nausea and fainting,—lead to local changes in the temperature of particular parts of the skin, without any corresponding depression of circulation or respiration. These facts can only be explained upon other hypotheses, with which we shall be made acquainted in the study of the nervous system. Although a fasting animal gives off less carbonic acid (§ 1139), still its heat generally rises rather than falls. Hence either the capacity of the animal tissues for heat (§ 200) is altered; or,—what is much more probable,—substances are consumed which can furnish a greater combustive heat. An increased oxidation of hydrogen (§ 208) might partly conduce to this effect. Future researches must decide whether something similar does not obtain in the hybernating animals; who, apparently, do not always cool in proportion to the diminished quantity of carbonic acid they give off. At any rate, it cannot be indifferent to the combustive heat, whether it is fat, a hydrate of carbon, or an albuminous substance which is consumed; or in what way the metamorphosis is effected.

1185. From the ultimate destinies of the inspired oxygen (§ 1123), it is probable that one part of the animal heat is produced in the blood; and another in the tissues, or in the nutritional fluid. While conversely, those tissues which are not traversed by any blood-vessels—such as the epidermis, the nails, and the hair—must receive their temperature chiefly by communication from these (§ 1177). And since they are bad conductors of heat, they will obstinately retain whatever they receive (§ 203).

1186. At present we do not know why one group of vertebrata has a higher temperature than another. In both divisions, the structure of the organs is on the whole similar. Hence the more rapid metamorphosis of substance in the warm-blooded beings can only affect the minute details of the process. The muscles and nerves of the cold-blooded animals generally preserve their vital properties with greater tenacity. They are less injured by the influence of low degrees of temperature than the same

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structures in higher vertebrata. Hence they are more constant, and less susceptible, agents of the most essential functions of life. The quicker metamorphosis of matter in the warm-blooded animals at once furnishes both more delicate substances, and those higher degrees of heat which are necessary to their action. The latter also favour the transit of fluids through the fine tubes of the different organs (§ 110); as well as the maintenance of the normal state of admixture in the blood and other juices (§ 1104), and many chemical changes which greatly influence absorption and secretion. In one word, we have a more laborious apparatus, the greater activity of which probably allows of more delicate and perfect operations, especially in the nervous system.

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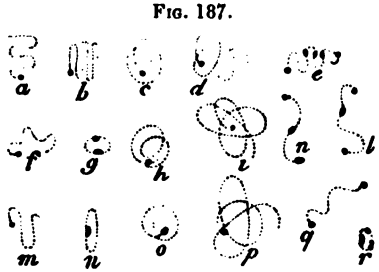
CHAPTER XV.

LOCOMOTION.

1187. Many of the movements seen in the animal tissues by the naked eye, or with the microscope, are also found in other departments of nature. Such are the diffusive currents formerly (§ 129) noticed, and the molecular movement observed by Brown. But there are others which are absent from minerals and the dead organic being; so that they form the expression of certain vital functions. Still movements which are either similar, or at any rate related to these, occur in both the kingdoms of organized nature—*i.e.*, in plants as well as animals. Thus the movements of the cilia and spermatic elements, and alterations in the form of simple contractile substances, occur in vegetables, although less frequently. Finally, those movements which necessarily or possibly obey the rule of the nervous system, belong exclusively to man and animals. They form one of the characteristics of these, the highest members of the creation.

1188. *The Brownian Molecular Movement.*—On looking at pigment-molecules (Tab. II. Fig. 28) mixed with water under a magnifying power of 350 to 550 diameters, almost every one of them is seen to be in continual movement. Many (*a*, *b*, *g*, *m*, *n*, Fig. 187) vibrate here and there as indicated by the dotted lines. Others (as *c*, *h*, *i*, *o*, *p*,) describe curves of different kinds, by means of which they return pretty nearly to their original place. Others (*e*, *f*, *l*, *q*,) proceed for a certain distance in curves or circles. Many only turn upon their axis in the way shown by the different forms represented in Fig. 187; at the same time moving through more (*a*, *k*, *l*, *q*,) or less (*g*, *r*,) additional space. The same globule of pigment may exhibit different movements at different times. If the fluid contains a large number of them, the whole reminds one of the moving atoms of dust which are seen in a ray of the sun, or of the restlessness of the numerous minute infusoria—*Bacteria or Vibriones*—which occupy a putrefying liquid.

Fig. 187.



1189. Similar phenomena are exhibited by the smallest fragments of

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most bodies, whether vegetable or mineral, when minutely divided and placed in a not too tenacious fluid. The liquid contents of cells sometimes offer the necessary collateral conditions. Where this is not the case, the reception of water by endosmosis (§ 129) may constitute the exciting cause. Hence we often find that the minute substances contained in some vegetable or animal tissues exhibit an active and protracted molecular movement.

1190. The crystals of the otolithes of the higher vertebrata (Tab. I. Fig. IV.) are a good example of the influence which bulk exerts upon these changes of place. Those of larger size lie quiet, while the smaller are in continual vibration. When a number of different substances are mixed with water, we generally find that it is the fatty and resinous matters which exhibit the most energetic movements. Hence molecules of pigment, or finely powdered asafœtida, are particularly adapted to these observations.

1191. We have seen that this molecular movement can only be recognised under high magnifying powers. Its velocity is therefore very small (§ 653). In point of fact, approximative estimates of time and space show that a molecule of pigment proceeds with a velocity of only $\frac{1}{6850}$th of an inch per second.

1192. Since the molecular movement is continued incessantly in a fluid which is to all appearance at rest, and since two neighbouring particles often vibrate in the most different manner, it follows that the phenomenon is not due to any strong and partial current. It has been attempted to explain the movement by the slow currents which accompany evaporation. But although, in some instances, these may perhaps increase it, still we may easily show that they do not constitute its principal cause. If a mixture of water and black pigment be introduced into a thin and small glass tube, and if this be hermetically sealed, evaporation will soon be limited to that which is caused by a change of temperature (§ 191). But, in spite of this, the molecular movement continues for many hours with great activity. And it is not suspended by oil or other fluids which do not evaporate.

1193. We may rather conjecture two other causes. We are apt to believe that no mechanical agitation disturbs the observation. But a more careful examination leads to a very different conviction. The walls of every building are in almost continual vibration; since their solid contiguous parts easily propagate the influence of the various movements caused by driving, walking, hammering, or the undulations of rapid currents of liquid. The beat of the heart, and the act of respiration, which visibly displace the observer's body (§ 641), render perfect quiescence impossible. And the small molecules which are shaken by these impulses will subsequently vibrate; during a period which is greater, the less force they can lose by collateral obstructions, or by way of communication (§ 66).

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A second cause lies in the temperature. When the closed tube just mentioned (§ 1192) lies on the object-plate of the microscope (*e*, Fig. 34, p. 59), certain layers of the fluid are nearer than others to the good conducting brass. The surrounding atmosphere which continually flows hither and thither, and the radiant heat of the observer's body (§ 210), are additional causes why many of the liquid particles become warmed sooner than others. These therefore seek to rise, while the colder masses descend. A series of slow alternating currents are thus produced, which are capable of impelling the minute molecules in a variety of paths.

1194. There can be no doubt that direct mechanical agitation, and indirect thermic movements, exert an important influence on the phenomena we are now considering. And although the results differ with the nature of the molecules and the fluid, still the mutual physical relations may assist to determine the amount of the original displacement, and the duration of the subsequent vibrations. The question whether these are the sole exciting causes, or whether the molecular movement is not based upon other attractive forces, cannot at present be decided. The forces to which it is due are at any rate easily overcome by the ordinary phenomena of adhesion (§ 112). Molecules of pigment which adhere to the glass wall of the tube by only a part of their surface exhibit no vibrations. But particles of camphor thrown upon water move very energetically until they are wholly or chiefly destroyed. While finely powdered salt which is mechanically diffused in a saturated solution of the same substance exhibits prolonged vibrations under the microscope.

1195. *The Ciliary Movement.*—When a small piece of mucous membrane from the palate of a newly killed frog is so folded up that its margin corresponds to its former free surface, a magnifying power of 150 to 255 diameters exhibits an appearance resembling that represented, on a larger scale, in Fig. 188. The ciliated epithelia are cylinders,

FIG. 188.

(*a*, Fig. 188; and Tab. II. Fig. 36) which stand upright or obliquely together, so as to make a kind of palisade. Their cilia (*c*) move so rapidly that it is impossible to recognise them singly; we can only see a number of them for an instant of time. They form a whirling border which occupies the margin of the fold. Hence molecules (*b*) which are mecha-

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nically diffused in the neighbouring fluid are hurried past with great apparent velocity in one or more directions.

1196. The ciliary movement occurs in many parts of other animals. Confining our attention for the present to the mammalia, it exists on the surface of the cerebral cavities,—and where such exist, in those of the spinal cord and olfactory lobe, especially of the embryo; in the lachrymal canals (*k l*, Fig. 150, p. 273), the lachrymal sac (*m*, Fig. 150), and the lachrymal duct (*n*, Fig. 150); in the Eustachian tubes (*f*, Fig. 128, p. 232), and in the mucous membrane of the nose (*a*, Fig. 128), with the exception of its lower part; in the supplementary cavities of the nose,—such as the cavities of the ethmoid bone, the frontal sinus, and the antrum Highmorianum of the superior maxillary bone; in the lowest part of the larynx (*i*, Fig. 128), the trachea (*k*), and the bronchial ramifications which penetrate the lungs; in the uterus and the Fallopian tubes of the adult female; finally, on the surface of the early ovum; and, possibly, in the capsules which surround the Malpighian tufts of the kidney (§ 396). In reptiles, there are many other structures,—such as the internal surface of the tympanum, the pericardium, the peritoneum, the mucous membrane of the mouth and œsophagus, the deciduous or permanent gills (§ 725), and certain portions of the cloaca,—which also exhibit the ciliary movement.

The amphibia, and many invertebrata—such as the snails and muscles—possess numerous ciliated membranes. But in the higher insects and *Arachnida*, they are altogether absent. The gills of the lowest ichthyoid reptiles, the *Sirens*, are clothed with cilia; while, with the single exception of the *Amphioxus*, those of fishes are smooth. Hence the presence or absence of the ciliary movement is not decided by the general arrangement of the organs, but rather by their special circumstances.

1197. Many of the infusory animalcules which form the lowest extreme of the animal kingdom possess hairy or prickly processes, which are more or less constantly in whirling motion, and are frequently governed by the volition of the animal itself. And since the ciliary movement of the higher animals is not under the control of the nervous system, this fact has been supposed to constitute an essential distinction between the two classes of structures. But the study of the simple contractile substances teaches us that this difference is less than it appears to be at first sight.

1198. Since the minute hairs of a severed fragment of ciliated membrane vibrate energetically (§ 1195), it is obvious that the phenomenon is alike independent of the circulation of the blood, and of the influence of the brain, spinal cord, or ganglia. If we scrape the surface of a ciliated membrane — such as the mucous membrane of the frog's mouth —the mass so obtained contains isolated ciliated cells (*a* and *b*, Fig. 189); together with aggregations of these. (Fig. 190.) The cilia of both often

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continue to vibrate for some time. Hence the maintenance of their mode of attachment is the sole condition of their activity.

Fig. 189.

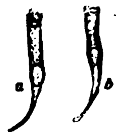
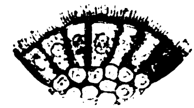


Fig. 190.

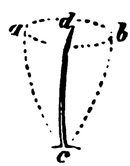


1199. The cilia are usually placed upon cylindrical epithelia (Tab. II. Fig. 36). But sometimes they occupy spherical cells,—as for instance, in the choroid plexus of the brain, or on the surface of the very young ovum or embryo. They may even be planted directly on simple membranes.

1200. The cilia of different animals do not always exhibit the same kind of movement. They are usually either flexed and extended like a finger (Fig. 191); or they describe a circle (*a b*, Fig. 192) with their point,

Fig. 191.

Fig. 192.



(*d*) and a cone (*a b c*) with their whole length. Contiguous cilia generally exhibit the same movement. The character of the total movement, and the currents which are produced in the neighbouring fluid, depend upon the situation, nature, and succession of the motion, of the several cilia.

1201. In a level ciliated border (such as that at *c*, Fig. 188,) the main current generally flows in a straight line (like the arrow opposite *b*). But many mucous surfaces possess small hillocks or papillæ, separated by valleys or furrows. Such an elevation is shown (strongly magnified) by Fig. 193. Where this is the case, we may often remark a correspond-

Fig. 193.

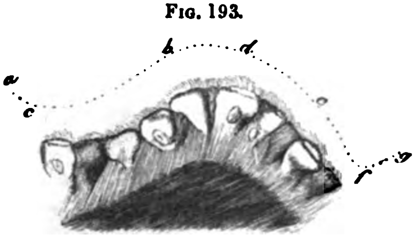


Fig. 194.

ing curve of the stream (*a b c d e f g*, Fig. 193). The conjoined action of neighbouring cilia which occupy different heights frequently leads to

movements such as are indicated by the arrows in Fig. 194. In this way many of the small bodies in the surrounding fluid are first impelled in curved paths towards the ciliated margin, and are then driven off in the contrary direction.

1202. Where the ciliated epithelia (*a*, Fig. 188) are fixed upon an immovable foundation, it is obvious that the cilia (*c*) can only propel the neighbouring fluid, and any small bodies (*b*) which may be contained in it. But if, on the contrary, a small piece of ciliated membrane be cut loose, it will often be itself displaced in the opposite direction to the main current, as shown by the lower arrows in Fig. 188. This phenomenon is a counterpart to the well-known fact of a boat going forwards when its oars propel the water backwards. Indeed, such a result is actually repeated when any very light body bears a large number of actively whirling cilia. In this way the minute ovum or embryo of many animals, as well as the mature individuals of some of the lower creatures, is enabled either to rotate continually, or to move in directions which correspond to the action of its cilia.

1203. In many ciliated membranes the main current takes a definite direction. For instance, in the mucous membrane of the rabbit's nose, molecules of ink, powdered sepia, or black pigment, are carried towards the nostrils; while in the larynx or trachea they are propelled towards the lungs. But in the tracheal mucous membrane of a puppy, Sharpey found the contrary course. The cilia of the Fallopian tube conduct small particles towards the uterus; or from within outwards. In the gills of Molluscs we sometimes see cilia, which have long maintained a motion towards the right, suddenly reverse their current towards the left. Sometimes this alternate play is repeated several times. In the gills of the *Ascidia*, J. Mueller remarked that the action of the cilia ceased, and recommenced after a certain interval of rest.

1204. The velocity of the ciliary current can only be determined approximatively, since the results are materially altered by the density of the contiguous fluid, by the weight of the small substances which it contains, by the nature of their movement, and, finally, by the activity of the cilia themselves. In the mucous membrane of the frog's mouth, blood-corpuscles and molecules of pigment are propelled with an average velocity of about $\frac{1}{200}$th of an inch per second. Their movement is therefore slower than that of the blood-corpuscles in the capillaries of the same animal's foot (§ 712); but quicker than that of particles in a state of molecular movement (§ 1191). Since these observations require a high magnifying power, the velocity of the movement appears to be greater than it really is (§ 653). Krause found that each cilium makes from 190 to 320 vibrations per minute. My own observations would give about 77 to 152 for the gills of muscles, and for the mucous membrane and lungs of the frog. Perty estimates 240

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to 300 for the subsiding ciliary movement on the outer surface of the *Alcyonella*, a fresh-water polyp.

1205. Rarefaction of the air does not stop the ciliary movement. But higher temperatures soon suppress it; and too great a degree of cold often has the same effect. Still a ciliated membrane may be plunged for an instant into water of 178° without causing the vibrations of the cilia to cease. The ciliated membranes of warm-blooded animals are more sensitive to low degrees of temperature than those of the cold-blooded creatures.

1206. The shock of a Leyden battery does not disturb the ciliary movement on the gills of the Muscle. If a large piece of such a membrane be laid between the two poles of an electro-magnetic machine (§ 248), many hundred shocks may be transmitted through it without producing any change in the current of most of its parts. It is only the places attacked by the electrolytic action — which sets free acids or alkalies — that suffer from the caustics thus produced. If a few ciliated epithelia be placed between the opposite poles of such a machine, at a distance of about $\frac{1}{25}$th of an inch from each other, after a short time their cilia cease to act.

1207. Water deprived of its air, or charged with large quantities of carbonic acid, does not destroy the ciliary movement. But a fluid which has absorbed much sulphuretted hydrogen exerts an injurious influence.

1208. Many soluble substances only injure the ciliary movement when they have a certain degree of density. Ordinary caustic ammonia annihilates it even when diluted 10,000 times; nitrate of silver, 1000 times; sulphuric æther, 100 times; and common salt, only 10 times. Hydrocyanic acid which is quite free from alcohol and sulphuric acid, and solutions of acetate of morphine or strychnin, do not check the movement. The blood preserves it longer than pure water. The bile, which is so liable to decomposition (§ 467), is always more injurious than saliva or undecomposed urine.

1209. In the frog, the ciliary current is often checked in a short time by the influence of cold water: this is especially the case with the epithelia (§ 1198) which have been removed by scraping. Under such circumstances the form of the ciliated cells is sometimes altered as a consequence of the absorption of water; so that they become surrounded with a transparent ring (*a*, Fig. 195). But in spite of this, their cilia often continue to vibrate.

FIG. 195.

1210. We have already (§ 1018) seen that young cells destined to the replacement of those above them are now and then met with beneath the ciliated cylinders. Some mucous membranes shed their ciliated epithelia at definite intervals of time. In treating of reproduction we

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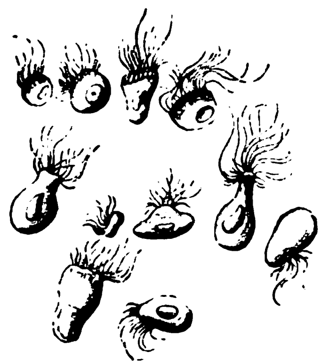
shall find, that the mucous membrane of the uterus loses its ciliary covering at each menstruation and pregnancy, and subsequently reproduces it. Many morbid conditions lead to a similar peeling of this covering in other parts. When a person gets a violent cold in the head, his nasal mucus at first contains a number of ciliated epithelia. Their form is frequently changed, as represented by Fig. 196. The secretion of mucus is disturbed; and the saline fluid which streams forth in large quantity operates like the water that enters by endosmose in the observation previously mentioned (§ 1209). But even here the cilia continue to vibrate for a certain time.

FIG. 196.



1211. The ciliary motion is often retained with great tenacity in the dead subject. In the mucous membrane of the rabbit's nose and trachea it sometimes continues 5 to 6 days after the death of the animal; in that of the mouth of the frog, 8 to 9 days; and in the œsophagus of the tortoise, 15 days. In the meantime decomposition advances so far that the whole acquires a putrefactive odour, and a somewhat mucous and diffluent consistence; and contains a large number of infusory animalcules. If a human trachea be excised some hours after death, and laid in serum (§ 1001) of not too low a temperature, the ciliary movement may generally be recognized for one or two days afterwards. And in favourable cases it may be seen that the movement of the cilia only ceases in consequence of their being either shed, or dissolved by putrefaction.

1212. Although the ciliary movement chiefly occurs in the animal kingdom, it may also be found in plants,—such as the lower cryptogamia. The seed-granules or spores of the fresh-water *Algæ* or *Confervæ*, and of the sea-wracks or *Fuci*, frequently whirl round actively in the water on emerging from their parent plant. After this movement has lasted some time, they sink to the bottom, to undergo their germinating process.

1213. The cilia which cause such movements may be arranged in three ways. Many tissues have but very few;—*e.g.*, two or four. These are sometimes so delicate that they can only be recognized after the use of alcohol or tincture of iodine. This, for instance, is the case with the small *Alga* (*Hæmatococcus pluvialis*) which is represented in Fig. 197; and which sometimes occurs in such quantities as to give a red colour

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to large portions of water. The sketch *a* was taken after the operation of alcohol; and *b c d* after that of tincture of iodine.

FIG. 197.

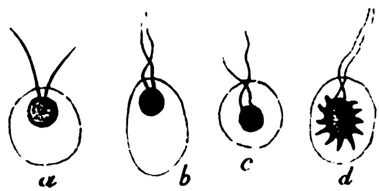
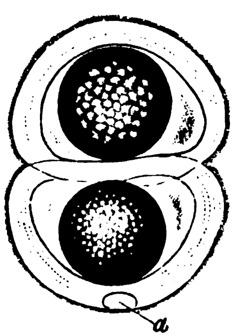


FIG. 198.

The second arrangement is exemplified by Fig. 198; which represents the entire spore of *Ectosperma* (*seu Vancheria*) *clavata*, surrounded by a continuous covering of cilia. They are so delicate that they can only be verified after their movements have been checked by the action of opium.

Finally, according to Decaisne and Thuret, the cilia are sometimes sustained, not by single spores, but by the common integument of many spores—or the episporium. An instance of this kind (*Pelvetia caniculata*) is represented, after these observers, in Fig. 199.

FIG. 199.



1214. We have already (§ 1201) seen that the action of the cilia is able to rotate and propel light substances of moderate size. But it is equally capable of propelling mucus and other fluids. Hence where the gills or integuments of an aquatic animal possess a ciliated epithelium, new quantities of the water which contains its respiratory air (§ 725) will be constantly brought into contact with its surface. In this way the cilia are made to assist the respiratory function. But none of these phenomena are sufficient to account for the wide distribution of the ciliated epithelia, or to form the objects to which they are chiefly subservient. It is probable that the disturbance produced by their movement leads to certain molecular operations at present unknown. And to these we may perhaps refer the peculiarities of their distribution.

1215. *Movements of the spermatic elements.* — The mature semen of animals generally contains certain bodies, which are capable of numerous movements. These are either spontaneous, or follow the application of water. Formerly such bodies were regarded as animals related to the *Infusoria* or *Entozoa;* and were hence named seminal animalcules or *Spermatozoa.* The growing conviction of modern times — that they are not independent beings, but belong to the tissues, — has

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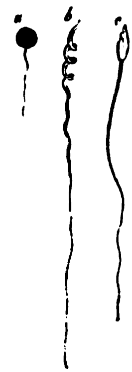
led to their receiving more suitable names:—such as spermatozoids, seminal filaments, seminal cilia, or moving seminal corpuscles.

1216. In the vertebrata, we meet with three chief varieties; which are represented in Fig. 200, magnified 255 diameters. The form *a* is found in many osseous fishes; *b*, in some of the cartilaginous fishes, and in birds; and *c* in the mammalia (Tab. V. Fig. 78). The anterior and thicker part is called the head or body; and the thinner posterior part the tail, or caudal filament.

Fig. 200.



1217. The elements of the mature semen exhibit some movement, even in the undiluted seminal fluid. But an application of water, blood-serum, or any other solution which is properly diluted, gradually increases this motion. In immature semen such an admixture must often be made, before any vibrations can be seen. And in many varieties of semen,—such as that of the river crawfish,—no trace of movement has ever been found at any period of their development.

1218. Where the body and tail are sharply defined (*a* and *c*, Fig. 200), we may see that it is only the latter which induces the movement; and that it appears to propel the former. Where the whole has a filamentous shape (*b*, Fig. 200), this statement only holds good when the anterior part is considerably thicker. The vibrations seem almost confined to the long and thin segments.

1219. The caudal threads of the mammalian semen (*c*, Fig. 200), may move like a pendulum to and fro; may wave up and down; may take a simple or serpentine curve; or may combine these elementary movements. At the same time, the whole structure vacillates in various directions. It is either driven forwards in a longitudinal path, or is contained for a time within a given space, which it traverses with various turnings and windings. To this are frequently added rotations of the particle around its long axis. The forms represented by *b* (Fig. 200) often press forwards like a corkscrew does into a cork. In all cases the head precedes the tail. The average velocity amounts to about $\frac{1}{685}$th of an inch per second; it is therefore considerably less than that of the ciliary movement (§ 1204).

1220. Cold appears to injure the seminal movements of the warm-blooded, more than those of the cold-blooded, animals. A great heat annihilates them altogether. But repeated shocks of the electro-magnetic machine (§ 248) do not disturb them. Acids and alkalies, alcohol, ether, and many salts, soon destroy them. Many varieties of mucus and urine do not exert this influence. Solutions of narcotic poisons which possess no chemical influence seem not to affect the activity of the seminal elements.

1221. The action of these structures lasts about as long as the ciliary

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movement (§ 1211). The human seminal particles have been seen to vibrate 84 hours after death, and those of the frog from 5 to 6 days after. The semen remaining in the testicle is much more favourably situated in this respect than that kept in any other fluid. The semen introduced into the female generative organs of some insects retains its movements here for many months.

1222. Just as a ciliary movement is sometimes met with in the vegetable kingdom (§ 1212), so the structures now under consideration repeat this distribution. What have been called seminal animalcules in the phanerogamous plants, are nothing but corpuscles of the fovilla of the pollen, which exhibit the Brownian molecular movement (§ 1188). But in the antheridia (or the organs resembling these) of the ferns, mosses, and *Algæ*, we find elements which are really seminal. For instance, if we examine a fine section of the mature antheridia of a large leaved moss under a magnifying power of 255 diameters, we see that each cell (*a*, Fig. 201) shelters an involuted seminal thread (*b*). Moistening it with water gives rise to a tremulous movement. When it emerges from the cell, the head (*b*) goes first. Many of these moving structures—as, for instance, those of the sea-weeds, and some large-leaved mosses — possess two threads, as shown at Fig. 202.

FIG. 201.

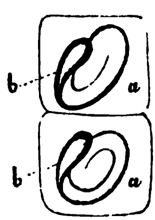
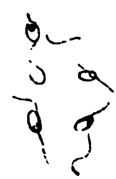


FIG. 202.



1223. If we confine our attention to outward form and capacity of movement, we shall find that filaments like those of the semen are not limited to this fluid. The skin of many polyps and medusæ, the contact with which excites such pain as to earn them the title of *Acalephæ*, or sea-nettles, possesses similar structures: which are enclosed in capsules, and, when set free, exhibit serpentine curves of their tails.

1224. *Simple Contractile Substances.*—The body of many *Infusoria*, *Polyps*, and *Entozoa*, and of the young embryos of most (if not all) of the higher animals, contains a simple gelatinous substance, which possesses a certain degree of contractility, and which, in these lower animals, is generally named *sarcode*. In the infusoria and polyps, the action of this substance is frequently accompanied by another phenomenon: viz. the production of cavities filled with fluid (*a*, Fig. 203, from *Loxophyllum meleagris*, *Duj*). When the mass contracts, these disappear from their previous situations, and reappear at other points. It may be conjec-

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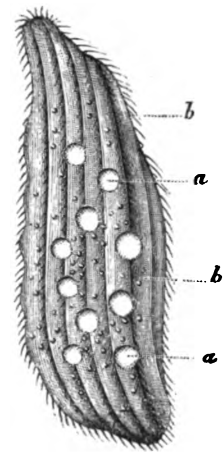
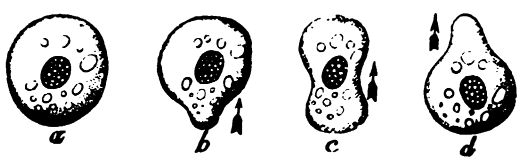
tured that a portion of the fluid which soaks the mass is pressed out from it at certain times, and taken up again by it at others. In the simple contractile substance of the vertebrate embryo this phenomenon has not hitherto been seen.

Fig. 203.



1225. Siebold and Koelliker have observed a peculiar periodical movement in the cells of the ova of *Planariæ*, at a certain stage of their development. Certain constrictions gradually proceed from one end of the cell towards the other, as represented by *a b c d*, Fig. 204. This alternate play of contraction and relaxation may be constantly repeated for many hours. Many other simple contractile substances,—such as the caudal vesicle of the embryo of some snails,—also exhibit periodical contractions under the microscope. Finally, the heart of the young vertebrate embryo beats most energetically, when as yet no muscular fibres can be recognized in its substance, but only a gelatinous basis with granules, nuclei, and cells.

Fig. 204.



1226. In many of the lower invertebrata, separated fragments of the simple contractile substance are also capable of active contraction. Hence contractility does not depend upon the mode in which the constituents of a tissue are connected with each other.

1227. Many of the tissues now under consideration are easily destroyed by the influence of the galvanic current. Many of the small infusoria suddenly burst under the shock of the electro-magnetic machine (§ 248); and the same effect may be produced upon the young larva of frogs. It may be conjectured that the chief cause of this phenomenon lies in the accompanying electrolytic effects.

1228. We are justified in supposing, that there are subordinate differences in the various tissues at present numbered in this class. It is probable that the sarcode of the infusory animalcule differs essentially from that of the young frog-larva, which is composed of cells. In the latter instance, the cell-contents, and the simple substance which unites the several vesicles to each other, demand a special consideration.

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1229. *Contraction of Muscular Fibres.*—Many of the lower animals, such as the *Rotifera* possess muscles which consist of a simple or faintly striated substance very similar to sarcode. But in most of the invertebrata, and all the vertebrata, the muscle or flesh is an aggregation of peculiar fibres, called the muscular fibres. In the higher animals we meet with two chief forms: the compound, transversely striped, or animal; and the simple, smooth, flat, unstriped, or organic muscular fibre.

1230. Every striped muscular fibre (Tab. IV. Fig. 54) consists of a number of longitudinal threads lying close to each other. Its surface exhibits a series of transverse striæ, which are generally very distinct, and remain visible even in alcoholic preparations. Indeed, in this state they are sometimes even more sharply defined than in the fresh condition. But in rare instances they are absent from some parts of the still irritable muscular fibre. They are easily deranged by putrefaction, which finally destroys them. A simple transparent membrane (Tab. IV. Fig. 54, *b*) called the sarcolemma or myolemma, encloses the whole, and separates one muscular fibre from another. On it are easily recognized numerous nuclei, especially after the application of acetic acid. The several fibres are collected together into bundles. These are separated by a *perimysium* of areolar tissue, containing vessels, nerves, and fat, and forming the non-contractile part of the muscle.

1231. On examining a thin section of unstriped muscular substance we find that a more or less decided striation indicates the direction taken by its fibres (Tab. IV. Fig. 59). Nuclei may also be remarked, especially after the whole has been moistened with acetic acid (Tab. IV. Fig. 61, *b*). And after tearing up a small piece with needles as finely as possible, we see numerous elongated fragments (Tab. IV. Fig. 60); many of which exhibit a nucleus, and resemble fibre-cells (§ 1055, compare Fig. 177, p. 318). These were previously joined lengthwise together to form the fibres, which are almost always smaller than the striped fibres of the same animal.

1232. The unstriped muscles are pale and yellowish to the naked eye; while the striped are distinguished by their fleshy redness in mammals and birds. But the muscles of many amphibia and fishes are white or yellowish, although their fibres offer very distinct transverse striæ. And some of the muscles of fishes, which are of a whitish-yellow colour when fresh, occasionally become red by the advance of putrefaction to a certain extent. Hence the colour is not an invariable characteristic.

1233. The course of the fibres leads to the same conclusion. Most of the striped fibres run close to each other without any mutual connection (Fig. 178, p. 320). But in the auricles of the frog's heart we find that a bundle (*a*, Fig. 205) breaks off from one fibre (*b*) to be applied to another (*c*). This course, which is the exception in striped muscles, is the rule

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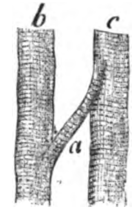
for the unstriped variety. The latter chiefly surround and enclose tubes, —such as the alimentary canal, the gall-bladder, the urinary bladder the uterus, the Fallopian tubes, and the excretory ducts of the larger glands. Here they form longitudinal and transverse layers, which cross each other at certain angles. The same arrangement is repeated in those striped muscles which occupy a similar position (*k o p m*, Fig. 72, p. 127, from the upper part of the œsophagus). But in most of the thick muscles of the trunk and extremities it is absent.

FIG. 205.



1234. The names of animal and organic muscular fibres (§ 1229) are based upon the notion that the striped variety is found in those muscles which are subject to the influence of the will; while the unstriped occurs in those involuntary organs which chiefly minister to the interchange of matter. But later researches have effected an important alteration in this theory. We shall hereafter see that the obedience of any part to the commands of the will depends upon its nervous structures, and not upon the nature of its muscular substance. It is true that in man and the higher animals, the organs provided with unstriped muscular fibres are generally not under the immediate control of the will. But the voluntary movements of many invertebrate animals, such as the snail and the muscle, are effected by unstriped muscular fibres. And as regards the striped fibres, the proposition does not even hold good for the vertebrata. The heart, and the lymphatic hearts of birds and amphibia, consist of distinctly striped fibres: and present red muscular substance, even when the muscles of the trunk and limbs are of a whitish yellow colour.

1235. In the human subject the following parts consist of striped fibres. All the free muscles of the head, neck, trunk, and limbs; the muscles of the eye; the small muscles of the ear; the tongue; the pharynx; the upper third of the œsophagus; the heart; the diaphragm; and the red contractile structures of the pelvis, and the organs of generation. Unstriped fibres are found in the following textures:—in the lachrymal sac (*m*, Fig. 150, p. 273), and the lachrymal canals (*k l*); in the iris of the eye (*c*, Fig. 150), and in the tensor muscle of the choroid; in many of the mucous membranes, in the two lower thirds of the œsophagus and the rest of the alimentary canal (*q s t u v y*, Fig. 124, p. 227), in the gall-bladder (*l*, Fig. 151, p. 280); and the spleen (*g*, and § 980); the urinary bladder (*x*, Fig. 124); the larger gland-ducts; the trachea (at *k*, Fig. 101) and ramifications of the bronchi; the biliary duct (*r*, Fig. 151); the ureter (Fig. 154, p. 285); the seminal duct (Fig. 154) and vesicles (Fig. 154); the prostate gland (Fig. 154), the uterus (*w*, Fig. 124, p. 227, *x*, Fig. 119, p. 208), the Fallopian tubes (*y z*, Fig. 119), and the vagina (*z*, Fig. 124); in many of the smaller glandular canals,—as, for example, in some of the cutaneous glands (Tab.

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IV. Fig. 62, *o p*); in the tissue of the corium (Tab. IV. Fig. 62, *d e f*), the dartos of the scrotum; the hair-bulbs (Tab. IV. Fig. 63); the vessels, &c. And although in many of the smaller gland-ducts no fibrous structure can be recognized, still we are justified in supposing that their transparent middle tunic (Tab. V. Fig. 65, *b*) possesses a certain capacity of contraction. It was formerly supposed that the ordinary areolar tissue (Tab. III. Fig. 40) was capable of active contraction; but recent observations have shown that unstriped muscular fibres are concealed here.

1236. The two kinds of muscular fibre are distinguished not only by their form, but by their mode of contraction. This circumstance is one of the chief causes of their distribution; while a second may probably be found in the relations of their nutrition and organization. Since the appearances presented by the striped fibres have been most accurately investigated, they will be first considered; and will be followed by a notice of the similarities and differences exhibited by the unstriped variety.

1237. Every muscle receives a number of nervous fibres, which are capable of exciting its contractility. They are therefore named motor fibres. If we take a prepared frog's leg,—*i.e.*, the skinned leg (*c*, Fig. 206) of a recently killed frog, from the thigh of which all the soft tissues have been removed, with the exception of the sciatic nerve, *a b*,—we may produce contraction of its muscles in two ways; by irritating the nerve, *a b*, or the muscular substance, *c*.

Fig. 206.

1238. The nerve *a b* is extremely sensitive towards mechanical irritations. The gastrocnemius muscle, *c*, contracts vigorously when we compress *a b*, or slowly cut it across. But if the section be too rapidly made, *c* may remain at rest. Mechanical stimuli applied directly to the mass of striped muscle, *c*, less frequently lead to marked contractions.

1239. Heat may either excite contraction or completely destroy it. When the nerve *a b* is dipped in water of 86° to 100°, the gastrocnemius *c* often contracts vigorously. Hence a sudden difference of temperature, or a quick alteration in the amount of warmth, exert an influence similar to that of a mechanical interference. In favourable instances this experiment may be repeated several times without injury. But if the whole preparation be sunk into water the temperature of which is higher than 104° to 113°, its muscles become paler and more brittle, and both their force and that of the nerve is permanently lost. At most, we only see some contraction at the first

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instant of applying the heat. The muscles of birds and mammals sustain a somewhat higher degree of heat; but even they will not bear hot water. This fact shows that the animal heat could not rise much higher than it appears really to be (§ 1165) without inflicting a serious injury.

1240. Cold weakens contractility, and finally destroys it. And hence the activity of a prepared frog may be raised or depressed at will, by placing it either between portions of ice, or in water at 99·5°. And by keeping it in water at 68° to 86°, its sensibility may be preserved for long periods of time.

1241. The motor nerves and muscular substance of the newly killed animal obey no kind of irritation with such delicacy and exactness as the fluctuations of the electrical current. When the act of establishing a current in the animal tissues raises the tension of electricity from zero to a given height, or when breaking the current brings it down from this point to zero (§ 233), contractions instantly follow. The first case occurs at the instant of closing the circuit (§ 232); and the second at that of opening it. Hence in the most favourable instances we have two contractions; one of closing, and one of opening, the circuit. If the tension of the current remain nearly unchanged during the closure of a weak galvanic circuit, and if all violent electrolytic action be absent, the muscles will remain at rest. Under these circumstances the electric currents which pass through the nerve (§ 216) only alter its condition gradually: as we shall hereafter find in treating of the nerves. But if, on the other hand, the strength of the current varies more considerably, or if powerful electrolytic influences interfere (§ 239), the muscles contract during the closure of the circuit.

1242. Electricity may be applied with this object in either of three ways. If we insulate (§ 217) the prepared frog's leg on a glass plate

FIG. 207.

(Fig. 207), its gastrocnemius may be made to contract, either by placing the two conducting wires (*c* and *d*, Fig. 50, p. 80) on two different points of the nerve *a b*, or of the muscle *c*; or, finally, by bringing one wire into contact with the nerve *b*, and a second against the muscle *c*. The two first cases imply a much higher sensibility than the last.

1243. We have already (§ 223) seen that the artificial or natural transverse section of the striped fibre (*a b*, *c d*, Fig. 208) is negative

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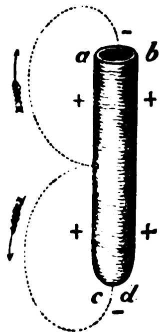
with respect to its longitudinal surface (*a c*, *b d*). We have therefore a kind of galvanic battery in the muscle itself. And since it responds to slight changes in the tension of electric currents by contractions, these may be excited by the mere influence of the animal tissues, without any metallic circuit.

FIG. 208.



1244. The simplest experiment consists in exciting contraction in the galvanic preparation by means of its own muscular substance. For example, if the nerve *a b*, (Fig. 206) be so bent round, that a part of it *b* touches the neighbouring artificial transverse section, when *a* is laid upon the longitudinal surface of the gastrocnemius, *c*, an electric current will pervade *a b*. The current passes in the direction of the upper arrow in Fig. 208. The muscle *c* therefore contracts at the instant of its quitting *a*, or at the moment of closing or opening the circuit (§ 1241): the contraction being due to the electrical tension of its own mass tending to become equalized by means of its motor nerve. Less frequently we may succeed by bringing one part of the nerve into contact with the longitudinal surface (*c*) of the gastrocnemius, and another part against the expansion of the tendo Achillis which occupies its lower extremity, and covers the natural termination of its muscular fibres (*c d*, Fig. 208).

1245. These facts illustrate the column invented by Matteucci. A certain number of the skinned thighs of newly killed frogs are so divided above and below as to admit of being joined to each other in the manner represented by Fig. 209. This will give us a negative artificial transverse surface (*a b*); and a positive longitudinal one (*b c*). If a prepared frog be now completely insulated (§ 217) by being placed in a glass tube (*a*, Fig. 210), while its nerve is allowed to hang out—and if a certain part of this latter be brought into contact with *a b*, Fig. 209, while another part of it touches a segment of *b c*,—the muscles of the prepared frog (Fig. 210) will again contract at the instant of opening or closing the circuit.

FIG. 209.

1246. The source of the exciting electric current is a matter of indifference. Not only the contactive currents just mentioned, but those of chemical or thermal electricity (§ 1164) are also successful. Electricity of tension or friction (§ 216) acts very powerfully on the prepared frog at the instant of being equalized; because its transition from the given elevation to zero (§ 232) occurs with great rapidity.

1247. When the successive closures and openings of the galvanic current succeed each other slowly, the muscles fall into a state of clonic

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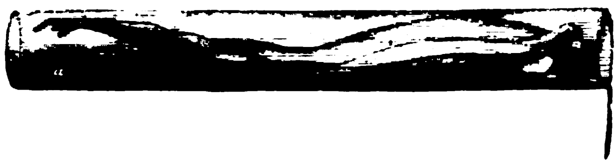
or alternating convulsion:—*i. e.*, we have first a contraction, then a relaxation; then another contraction, followed by another relaxation; and so on. But when, on the contrary, the closure and opening of the current are repeated more quickly, we get stiff or tonic convulsions:—*i. e.*, the

FIG. 210.



muscles remain constantly contracted. But if this should continue too long, or if the muscular substance did not originally possess any great degree of susceptibility, alternating convulsions occur; either in the whole muscle, or in some of its fasciculi. The electro-magnetic (§ 248) and magneto-electric machines (§ 252) are best adapted to a rapid and alternate opening and closure of the circuit. And hence with the help of such apparatus, tonic convulsions may easily be produced.

1248. Soon after excision, the vigorous muscles of frogs may exhibit tonic or rigid convulsions, with an average of only two strokes of the machine per second. But a smaller number at once gives rise to alternating contractions.

1249. The same difference also obtains with other irritants. If the nerve (*a b*, Fig. 206, p. 368) be gradually constricted by a thread, the successive irritations thus produced will sometimes excite rigidity of the gastrocnemius. Hence this kind of muscular contraction does not depend on a special character of the electric stimuli, but solely on the rapidity of their succession. A complete and visible relaxation of the muscular fibres requires more time than intervenes between every two stimulations. At present we are ignorant whether anything similar occurs in the continuous contraction of a muscle during life.

1250. The results of galvanic irritation are intimately connected with the condition of the motor nerves. It is this which determines whether the contractions occur only on closing or on opening the circuit, or on both of these occasions; and whether the effect is independent of all change in the direction of the current. But the further illustration of these facts belongs to the study of the nervous function.

1251. A prepared frog which has been kept some time in a rarefied space, or in an atmosphere of hydrogen gas, or in a mixture of ordinary air and sulphuretted hydrogen, is still capable of contracting vigorously under the influence of the electro-magnetic apparatus. Even water which has absorbed the latter gas does not at once destroy its irritability. But on a longer application it is more injurious than pure

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water. The vapour of acetic acid acts very injuriously: and that of ammonia is still more hurtful.

1252. Irritability is at once destroyed by alcohol, ether, or solutions of acids or alkalis which are not too dilute; as well as by solutions of nitrate of silver. Very weak fluids of this kind are capable of exerting two effects;—temporary excitement, or permanent destruction. So that here also we meet with an alternation of results like that already (§ 1239) seen to be produced by heat.

1253. A motor nerve may be brought into contact with a pure watery solution of hydrocyanic acid or strychnin without losing the influence which it exerts upon muscular contraction. But if alcohol form the solvent, or if the prussic acid contains the usual admixture of sulphuric acid which prevents its decomposition (§ 299), the injurious effect soon appears. The watery solution of opium also acts injuriously.

1254. We have seen (§ 1237) that a striped muscle contracts on irritating it or its motor nerve. In the latter case, a change in the molecular state of the nerve is propagated along its fibres to their terminations in the substance of the muscle. And this again produces that peculiar alteration in the physical condition of the muscle, of which contraction forms the outward expression.

1255. When a stimulus—for instance, an electric current—is applied to the muscle itself, the result admits of two explanations. We may first suppose that it directly stimulates the muscular fibres; and that these do not require the mediation of the nerves, but possess an inherent irritability or susceptibility of their own. Or secondly, we may regard the electric current as acting directly upon the nerves which are distributed in the interior of the muscular substance. It is thus essentially the same thing as if the nerve itself had been stimulated. The molecular change in the nerve produces the physical alteration in the muscle; which latter is incapable of direct contraction, and can only accomplish it by an intermediate action of the motor nerve-fibres.

We shall hereafter find reasons for conjecturing that the unstriped muscular fibres possess an independent capacity for contraction, and do not require the aid of the nerves; or, at any rate, not of those primitive nerve-fibres which possess oily contents. But at present we have no means of deciding whether the striped fibres, which are so much more obedient to the nervous influence, resemble the unstriped in this respect.

1256. Many have laid great stress upon the results obtained by the section of nerves. After the sciatic nerve (*a b*, Fig. 206, p. 368) or the lumbar plexus has been divided in a living frog, the corresponding muscles—for instance, the gastrocnemii—are no longer capable of contraction in obedience to the will. At first, however, the application of an electric current to the inferior segment of the nerve, or to the paralyzed muscles themselves, is followed by vigorous contractions. But if the

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nerve is not reproduced (§ 1066), it subsequently becomes incapable of exciting any contraction; while by applying the poles of a galvanic circuit to the muscle itself, these are constantly produced. The prepared frog (§ 1237) exhibits the same results. In the gradual destruction of irritability there finally comes a stage, during which the muscles respond by contractions to a direct stimulus, while irritation of the nerve is attended with no results (§ 1242). From these facts it has been concluded, that the muscular fibres possess an irritability which is inherent to their substance, and which therefore enables them to contract after the destruction of their nerves. But a more careful study of these phenomena will show that they do not warrant this conclusion.

In treating of the nerves we shall find, that the activity of their terminal distribution in the muscular substance endures longer than that of their trunks. When these latter no longer respond to stimuli, the branches which pass between the muscular fibres (§ 1255) still preserve their powers. The later disappearance of irritability in the muscular substance therefore admits of a double interpretation (§ 1242).

1257. Serious disturbances of nutrition also destroy the vital functions now under consideration. A nerve-fibre, the oily content of which has coagulated (Tab. V. Fig. 69), is no longer capable of exciting any movements. There is also a certain degree of decomposition of the living muscular fibres which involves the destruction of their contractile power. Under such circumstances they appear paler and softer; although they may still exhibit transverse stripes. The muscles of limbs which have been long paralyzed sometimes fall into this state. A better nutrition may again restore their powers.

1258. But these injurious changes only take place slowly. Hence interruption of the current of the blood disturbs irritability less than might be expected. Of course the circulation ceases in the galvanic preparation (Fig. 206, p. 368). But in spite of this, the contractility of the muscles, and the capacity of the sciatic nerve to excite contractions, remain many days. The whole preparation is often so exhausted by successive experiments that the effects cease. But on allowing it to rest for some time, it recovers from these effects of stimulation. So that this recovery of the nerve and muscles does not require the supply of fresh blood.

1259. On tying the abdominal aorta of a dog, the half-lamed animal drags its hind legs, to which the access of blood has been obstructed. This effect is afterwards greatly diminished. And if only one artery be rendered impervious, it is frequently absent. On the other hand, Brown-Séquard states that the local sensibility of the muscles of a rabbit's hind legs was lost a few hours after the ligature of its aorta, but reappeared soon after the circulation was restored.

1260. In the dead bodies of most animals, three conditions of the mus-

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cular substance succeed each other. There is first a space of time, during which the muscles retain a greater or smaller residue of their vital activity, or of their capacity of contracting under the influence of proper stimuli. They next experience an extraordinary contraction, which gives rise to that peculiar phenomenon called the *rigor mortis*, or the stiffening of death. Finally, as putrefaction advances, the muscular substance softens, and dissolves with more or less rapidity.

1261. The muscles of amphibia are especially distinguished by the obstinacy with which they retain their contractile powers. On this account frogs are selected for galvanic and other experiments on irritability. The femoral muscles of a frog frequently respond to the shocks of an electro-magnetic machine three days after death; and sometimes even from 5 to 6 days after. The muscles of the head, trunk, and fore-legs, usually die sooner. A decapitated turtle may move its limbs in answer to an external stimulus about 14 days after death.

Many fishes present a similar though less marked tenacity of irritability. Hence the well known fact that pieces of a fish which has been killed many hours before may spring out of the kettle.

1262. Irritability generally disappears much earlier in the dead bodies of mammalia and birds, than in reptiles. In very young mammals, however, its duration is longer. And in persons who have been executed, or who have died of diseases which do not involve degeneration of the fluids, we sometimes find certain of the muscles remaining irritable 15 hours after death. The best means of ascertaining this fact is by galvanic currents. But the supposition that these may be used to distinguish real from apparent death soon after the last breath, is obviously erroneous.

1263. These phenomena are greatly influenced by temperature. We have already noticed the effect of low degrees of heat on the irritability of the prepared frog (§ 1240); and in warm-blooded animals it is still more remarkable. When the corpse of an adult bird or mammal is rapidly cooled by collateral causes, the irritability of the red muscles disappears in a few minutes. Many narcotic poisons, such as hydrocyanic acid and wourali, lead to the same result; especially when introduced in large quantities.

1264. In addition to this, the duration of irritability in some degree depends on the character of the muscular fibres. Just as these are paler in the amphibia and fishes (§ 1232), so they are yellowish or less red in newly-born mammals, which retain irritability longer (§ 1262) than adults of the same species. It has often been stated, that the necessity of respiration is inversely as the tenacity with which the muscles retain their irritability. But future researches must decide the accuracy of this proposition. Although the smaller mammals consume more oxygen (§ 1180), and cool more rapidly, still their irritability does not

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always disappear with a rapidity proportional to the amount of combustion which occurs during life.

1265. Irritability is, as it were, dissolved by the *rigor mortis*. The former is the last relic of life; the latter, the first stage of spontaneous decomposition. The muscular substance then changes its physical properties. It becomes shorter, more solid, and less extensible. A muscular fibre which has lapsed into the state of *rigor mortis* has for ever lost its living force of contraction. But the change does not occur simultaneously in all the muscles of the body, nor even in all the bundles of the same muscle. Hence galvanic currents which excite contractions in one part, may have no effect on another part of the same muscle.

1266. A stiffened human corpse generally offers many peculiarities of attitude. The lower jaw drops immediately after death; but during the *rigor mortis*, it again approaches the upper jaw. The fore-arm is bent against the upper arm; and the leg against the thigh. The strongly bent fingers partially cover the flexed and adducted thumb. Any attempt at forcible extension tears some of the muscles before bringing the limb to a straight line.

1267. We shall hereafter see, that there are other structures besides the striped muscular fibres which undergo a *rigor mortis*. The peculiar positions just mentioned chiefly depend upon the mechanical preponderance of the powerful flexor muscles of the limbs over the extensors. Cutting across the muscles restores the mobility of the limb; a result which is not produced by severing the greater part of the articular ligaments.

1268. In the human subject, signs of the *rigor mortis* may appear in the first quarter of an hour after the last breath. Under the most unfavourable circumstances, it only occurs about 18 hours afterwards. When it appears later, it frequently lasts longer. Still we often find exceptions to this rule; as, for instance, according to Bruecke, in animals who have been poisoned by strychnin. In the corpses of men who have died suddenly the rigidity is generally very great: while in those of dropsical subjects it is but inconsiderable. Paralysed muscles always undergo a *rigor mortis*, unless their minute structure has suffered too much during life.

1269. The stiffness usually begins at the head and neck; and thence passes gradually downwards. But sometimes the thighs seem to lose their flexibility before the arms.

1270. The progress of putrefaction again softens the muscles, and renders them rotten. Hence they are easily torn by a moderate extension. The transverse stripes are subsequently deranged, and finally disappear. The fibres are longer recognized. Many of them present a finely granular precipitate. Finally, the nuclei of the sarcolemma (Tab. IV. Fig. 54, *b*) become invisible, even on the addition of acetic acid. The whole is at last

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converted into a dirty greasy substance of a greenish or brownish colour. In exceptional cases, a large portion of the soft tissues of a corpse becomes converted into a waxy substance, which resembles fat, and is thence called *adipocere.*

1271. Hitherto we have only considered the changes which the striped muscular fibre exhibits to the naked eye. We have now to examine into its more minute circumstances.

1272. When a muscle of a newly killed animal is cut across, its two surfaces separate from each other, so as to leave a certain interval. If this experiment be repeated at any point of either of these portions, the same phenomenon occurs, although usually with somewhat diminished force. On examining a thin and isolated piece of muscle (such as a piece of the abdominal muscles of the frog) under a moderate magnifying power, we see that the course of its fibres is not straight, but in zig-zags. These often correspond to each other in neighbouring fibres, as is shown by Fig. 211. But in other cases, the greater independence of the several fibres produces a want of uniformity in this respect. Fig. 212 represents an example of the latter kind.

FIG. 211.

FIG. 212.

1273. These zig-zag bendings may diminish the length of a muscle by $\frac{1}{8}$ to $\frac{1}{2}$. Under such circumstances, the angle of the plications varies from 50° to 108°. Still we sometimes meet with curves which are so slight, as scarcely to deviate from 180°. In the muscles of the frog we often find folds which are almost rectangular, and which would cause a shortening of about $\frac{3}{10}$ths of its whole length.

1274. The forms represented above are absent from muscles in an advanced stage of spontaneous decomposition. It is probable that the intermediate *rigor mortis* renders their occurrence impossible. But they are often found in muscles which are no longer capable of contraction under the influence of the galvanic current.

1275. Formerly these zig-zags were generally regarded as expressing the capacity of contraction present during life. Thus, under favourable circumstances, an examination of some of the hyoid muscles of the frog proves that, according to the state of the respiratory movements, the muscular fibres are either folded up in angles of this kind, or are again

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extended. But Ed. Weber has shown that the whole phenomenon is caused by elasticity, and not by vital contraction. Thus, for instance, if a thin membranous portion of frog's muscle offering the appearance represented in Fig. 211 be thrown into a state of tetanic rigidity (§ 248) by the electro-magnetic apparatus, we may sometimes see that the muscular fibres are extended perfectly straight. At the same time the whole mass becomes shorter, broader, and thicker. When the electrical action ceases, the muscular fibres spring back into their former situation, and the zig-zags again come into view.

But in many cases this decisive result is wanting. It sometimes happens that only a few of the muscular fibres really contract. These may then draw with them neighbouring fibres which have already lost their vital properties, and may thus either strengthen or level their folds. When contractility is considerably diminished, it becomes incapable of completely removing these zig-zags. Hence they become smaller, and approach 180°. In one word, they only form the expression of a contest, in which elasticity overcomes the remaining traces of contractility.

1276. When an extended silken cord or a violin string is cut through, it is twisted round by its own elasticity. Many fibrous tissues exhibit the same phenomenon. In their natural situation, they undergo a certain extension. The act of division frees them from this compulsory state. In this way are produced the wavy curves exhibited by the bundles of white fibrous tissue under the microscope (Tab. III. Fig. 40), as well as the zig-zags of the muscles (Figs. 211 and 212). Peculiar shapes are here produced by the form, size, character, and mutual connection of the tissues.

FIG. 213.

1277. There is reason to suppose that many other phenomena belong to the same class. Many muscular fibres exhibit deep constrictions (Fig. 213); and the transverse extremities of others offer a variety of peculiar forms (Fig. 214). These may even occur in muscles which are approaching the state of *rigor mortis*. Sometimes isolated and fresh muscular fibres curl up under water (Fig. 215), or even vibrate to and fro like a pendulum. It may be conjectured that the latter phenomenon, which has been remarked in the muscles of insects,—like many undulating movements which occur in those of the river crayfish under similar circumstances,—is not due to mere capillary attraction (§ 119, *et seq.*), but to certain relics of the vital functions.

1278. Microscopic research proves that the transverse stripes of the frog's muscular fibres approach each other at the instant of contraction.

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But there are other important changes which we are unable to verify. Here, as in many other molecular phenomena, the main fact escapes the eye, and can only be deduced from accompanying circumstances.

FIG. 214.

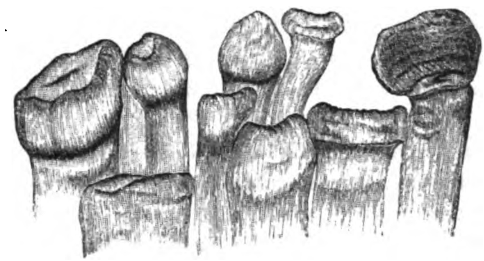
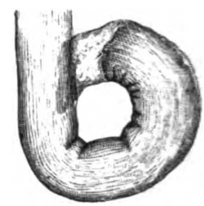
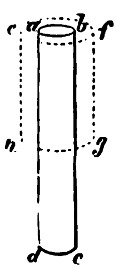


FIG. 215.



1279. The muscular fibre becomes shorter and thicker during contraction; its transverse diameter being increased at the expense of its length. Supposing that its form is in both cases cylindrical, it will correspond to *a b c d* (Fig. 216) in the relaxed, and to *e f g h* in the contracted state. Under such circumstances one of two things may occur. The contents of a cylinder are the product of its height (*a d*) by the area of its transverse section (*a b*). Now since *a d* is converted into the shorter *e h*, and *a b* into the larger *e f*, these relations may so compensate each other that the capacity of the cylinder remains unchanged. Assuming *a d* to be an inch, and *a b* a square inch, the volume of the cylinder will amount to one cubic inch. Now if, at the moment of contraction, *a d* is altered to *e h*, or ½ an inch, while *e f* enlarges to two square inches, the new cylinder *e f g h* will still contain one cubic inch. Hence the muscle will only have been altered in diameter, and not in capacity. The second possibility is, that all these proportions are altered:—that a condensation of the muscle leads to a diminution of its volume, or its extension to an enlargement.

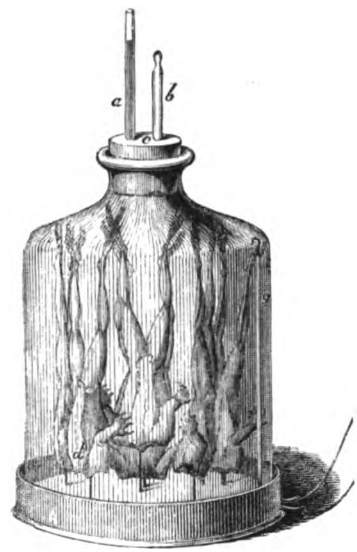
FIG. 216.



1280. The way in which this question has been inquired into may be represented by Fig. 217. A certain number of frogs are first beheaded, skinned, and gutted as shown at *d* and then stuck upon wires, which converge to one of the two conducting wires:—for instance, to *f*. The second conductor is continuous with *g*, which is free at its extremity, but is elsewhere covered with sealing-wax. The inverted bell-glass is closed by a stopper, *c*, which is perforated by two small tubes, *a* and *b*. Lukewarm water is poured in at *a*, while the compressed air escapes at *b*. When the fluid rises so high as to flow out of the open end of the shorter tube *b* by means of the hydrostatic law of equal pressure (§ 81), the aperture at *b* is hermetically closed. Special care must be taken that

no air-bubble of any size remains adhering to the frogs *d*, the wires *d g*, the inferior surface of the stopper *c*, or anywhere else: since the compressibility of gases (§ 67) could thus produce a diminution of volume which might be ascribed to other causes.

Fig. 217.



If *f* and *h* be now brought into contact with the two poles of a galvanic column, or of an electro-magnetic apparatus, the muscles of the prepared frogs contract, and the legs are powerfully extended. If the muscles now occupy the same space which they exhibited before the contraction, the level of the column of fluid at *a* will be no way altered. While it will be depressed by condensation, and raised by expansion. The application of a scale at *a*, and an examination by means of a magnifying-glass, will inform us of the smallest change in this respect.

1281. All the observations hitherto instituted concur in the statement, that no important difference of volume can be observed. Prevost, Dumas, and Matteucci, found no alteration of capacity in the case of the frog and the torpedo. The author sometimes found variations; which, however, scarcely amounted to $\frac{1}{10000}$th of the whole capacity. Weber, who experimented on an eel by means of the rotatory apparatus, remarked a trifling decrease of volume.

1282. Even after all air-bubbles have been removed, the too frequent transmission of electric shocks may easily give rise to deception, since these exercise an electrolytic action on the surrounding fluid, and cause bubbles of gas to collect on one of the conducting wires:—for example, on the point of *g* (Fig. 217). Be that as it may, we can at any rate state that there is no important alteration of volume at the instant of muscular contraction.

1283. A contracted muscle feels harder than a relaxed one. But the accurate researches of Edward Weber have taught us that this phenomenon depends solely upon the increased tension of the muscular fibres. Their substance itself becomes rather softer than harder. The amount of their elasticity is diminished instead of increased. We may convince ourselves of this remarkable fact in a variety of ways: but perhaps the best will be a simple experiment by means of the apparatus used by Weber, which is represented in Fig. 218. The hyo-glossus muscle of a

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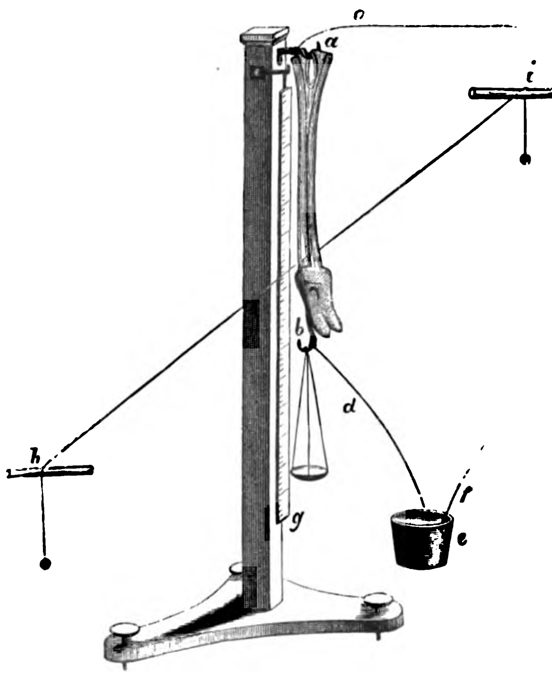
frog is fastened above to the metal hook, *a*; and below, it sustains the hook, *b*, which carries a small scale and weight: while a filament of raw silk, *h i*, is passed through the lower part of the muscle. This filament, which runs over two sticks, and carries a small weight at each end, serves as an index for the millimeter scale, *g*, placed behind it. Its situation may be read off by means of a magnifying glass.

FIG. 218.



One of the conducting wires, *c*, goes from the upper hook, *a*; and the second, *d*, from the lower one, *b*. This is permanently connected with one pole of the electro-magnetic apparatus (Fig. 58, p. 87). The second, *d*, dips into the mercury contained in *e*. When this also receives the second pole, *f*, of the electro-magnetic apparatus, the electric shocks pass through *d b a c*. The filament of silk, *h i*, is raised by the contracted muscle: and the difference between the present and former length may be read off with a magnifying glass on the scale *g*.

Let us suppose that in the state of rest the distance from *h i* to *a* equals one inch. Under the influence of the electro-magnetic apparatus this is gradually reduced to its minimum. If the apparatus continues to act, the muscle becomes partially relaxed, and then shortens again. Subsequently its length continually increases. But if we cease to apply the electric shocks when the distance again amounts to one inch, we shall

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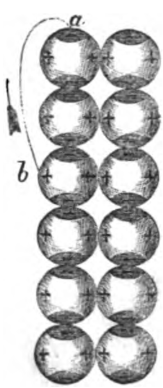
find that, in spite of this, the filament $h\,i$ descends to 1·05 or 1·1 inches. Now the weight which keeps the muscle extended,—viz. the scale and the weight which it contains, — has remained the same. And hence this considerable elongation of the muscle can only depend upon its having meanwhile become more soft and yielding. In other words, its index of elasticity (§ 55) is diminished.

1284. A series of comparative researches further shows, that this phenomenon depends upon the vital contraction, and not upon any physical circumstances. Thus although when the dead muscle is loaded with a weight, it also undergoes a gradual extension, still small weights require much longer intervals of time in order to produce results equal to those which are furnished in a minute by contraction. When a dead muscle is exposed to the shocks of the electro-magnetic machine, it is not softened:—a proof that this change is not produced by electrolysis. And the softening often has a visible proportion to the amount and duration of contraction in the living muscle. When this has been exhausted and softened by continual irritation, a rest which restores its contractility to any considerable extent also increases its elasticity.

1285. It is probable that, even during life, a fatigued muscle is more yielding than when fresh and vigorous. Still the feeling of fatigue does not depend upon this, but upon certain conditions of the nerves, to which we shall return in speaking of the nervous system. Here also we find circumstances which resemble those of the sensations of warmth (§ 1175). A sick person, whose muscles exhibit their normal characters, may feel so prostrated as to be ready to drop from exhaustion.

FIG. 219.



1286. At the instant of muscular contraction, the electric state is also changed. We have seen (§ 223) that the muscular current chiefly depends on the fact, that the longitudinal surface is relatively positive, while the natural or artificial transverse section is negative. We may therefore suppose that the muscular fibres consist of molecules, which are positively electric at their sides, and negatively electric at their ends; as exhibited by the diagram in Fig. 219. If we connect *b* to *a* by means of a suitable conductor, in which a galvanometer (Fig. 43, p. 76) has been interposed, the positive current will set out in the direction of the arrow in Fig. 219. The needle of the galvanometer will also deviate in this direction, and after it has finished vibrating, will remain fixed at a definite number of degrees on the positive side of the circle. While according to Du Bois,[39]) when the muscle,—for instance, the separated gastrocnemius of a frog,—falls into a state of tetanic rigidity from the sciatic nerve being exposed to a rapid succession of electric shocks, the needle recedes,

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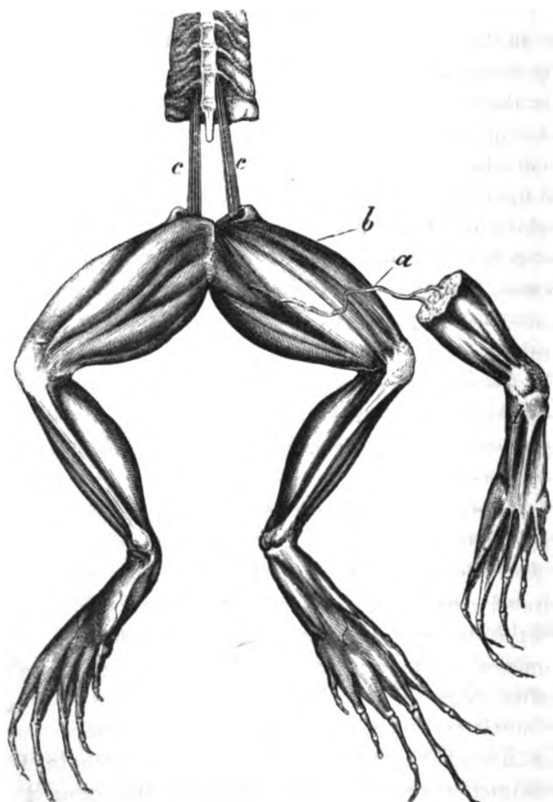
glides past zero, and passes over a certain extent of the negative half of the graduated circle. The contractions which accompany mechanical disturbance of the spinal marrow, or are produced by mechanical, thermical, or chemical irritation of the sciatic nerve, may give rise to similar (though less marked) results. Hence at the instant of powerful contraction the muscular current is visibly diminished. And here again accurate observations show that the phenomenon does not depend upon accidental collateral circumstances, but upon the vital contraction itself.

1287. This fact has been applied by Du Bois to explain what Matteucci has described under the name of the induced contraction. If the sciatic nerve *a* (Fig. 220) of one prepared frog, *d*, be made to rest

FIG. 220.



upon the femoral muscles, *b*, of a second, and if the corresponding sciatic plexus, *c*, be galvanized with the apparatus represented in Fig. 221,— which is a zinc plate, *a*, connected with a copper one, *b*, by means of a

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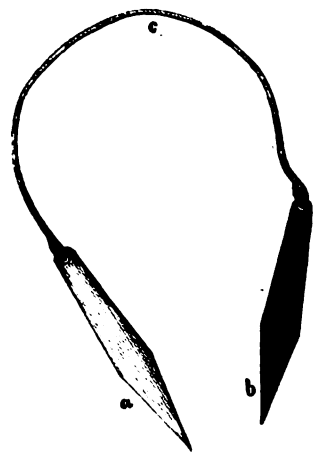
twisted copper wire, *c*,—not only the femoral muscles at *b*, Fig. 220, but also those of the muscles belonging to *d*, will contract. In susceptible preparations, this experiment may be successfully repeated several times, —even when the whole lies upon the table without being insulated by a glass plate, or when the nerve *a* is only laid along the outer surface of the femoral muscles, and *c* is only electrified in a short extent of its course.

FIG. 221.



Since the different parts of the length of a muscle possess different electrical properties (§ 223), so long as the nerve *a* lies upon the muscles, it will be permeated by a weak current. Electrical irritation of *c* excites a contraction of *b*, which changes its previous electric condition (Fig. 220). Thus we get a variation of current for *a*, which is answered by a contraction of the corresponding muscles at *d*. Hence the induced contraction consists in the fact, that the prepared frog is *rheoscopic: i. e.*, that it tests the current, and indicates its negative variation by contraction.

1288. The longitudinal surface and the transverse section present a greater electrical opposition than two dissimilar points of the former only (§ 223). It might hence be expected that the induced or secondary contraction would occur more easily when one part of the nerve (*a*, Fig. 247) touched the longitudinal surface, and a second the transverse one of *b*. And Du Bois states this to be the fact. Electrical irritation of *c* (Fig. 220) succeeds with most certainty. But mechanical, chemical, or thermical stimuli sometimes produce the same effect. Still they fail much more frequently. This strange fact evidently depends on peculiar collateral circumstances. For the mere use of the simple circuit represented in Fig. 221,—which produces a simple galvanic contraction, without continuous tetanic rigidity,—always causes the secondary contraction of any suitable preparation.

1289. It is evident that when a lamina of glass or any other insulating substance is brought between the nerve *a*, and the muscles *b*, the secondary contraction at *d* will cease. But a thin layer of moisture soon evokes it. Laminæ of silver, gold leaf, or other conducting substances, do not destroy it. If the nerve of a third preparation be laid upon *d*, a tertiary contraction may be produced; and through this, a quaternary one: and so on.

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1290. The general result of all this is, that at the instant of contraction the cubic capacity of the muscles alters but very little. The act of contracting renders them softer, and diminishes their muscular current. These facts indicate a great change in their molecular relations. In studying the function of innervation we shall see how far this change of physical characters resembles, and differs from, that produced by magnetism.

1291. In the vigorous contractions of striped muscles, the change usually affects their whole length in an instant. This statement may be verified in all the free muscles of the living body; and in vigorous excised portions of the frog's muscles, it may sometimes be seen under the microscope. But there are some exceptions to this rule, even in muscles which exhibit a distinct transverse striation.

1292. When the nerve (*c*) of the prepared frog represented in Fig. 220 is exposed to the continuous action of an electro-magnetic apparatus, we first obtain tonic spasms of the muscular substance,—for instance, of the femoral muscles (*b*). But after this state has continued a certain time, it is interrupted by alternating convulsions of some of the muscular bundles (§ 1247). Sometimes these contractions appear to be limited to certain portions of their lengths. A similar appearance is not infrequently offered by isolated and feeble portions of muscle when subjected to electric irritation under the microscope.

1293. The upper third of the human œsophagus contains very distinct striped fibres. In many animals,—for instance in the rabbit,—these descend to the cardiac aperture of the stomach. We have already (§ 381) seen that, at the instant of deglutition, the œsophagus of living mammalia exhibits undulatory movements; which consist of a local and progressive alternation of contraction and relaxation. The descending muscular fibres do not contract at once, but in successive segments (See Figs. 71, 72, 73, p. 127). In short, we have here undulatory movements, which resemble those of most unstriped muscular fibres (§ 399).

But a more careful examination teaches that, in certain cases, the striped fibres of the œsophagus act more conformably to their nature,—that they are only compelled by circumstances to these undulatory contractions. On breaking up the spinal cord of a mammal, no vermicular movements of the œsophagus appear. When the shocks of the electro-magnetic apparatus are transmitted through the cervical trunks of a dog or rabbit which has been killed in this way, the whole œsophagus falls into a state of tonic spasm, and becomes shorter and thicker. Indeed, we have already seen (§ 383) that the continuous progress of these undulatory movements depends upon collateral causes connected with the nerves.

1294. The nerve-fibres which are distributed in the interior of a muscle enter it at certain distances of its length. Thus each of them has under its influence a certain number of molecules of muscular substance, by which it is obeyed. When the entire muscle contracts, one of

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two things may occur. The stimulus may either be applied simultaneously to the whole mass, or may be propagated with extreme velocity from one nerve-fibre to another. The latter supposes a mere succession, with extremely minute intervals. The undulatory movements of the œsophagus may be partly due to the nerve-fibres acting in a slower and more ordinate succession. The local alternate convulsions which are finally caused by the electro-magnetic apparatus are partially explained by supposing some nervous fibres to be exhausted sooner than others.

1295. Many of the essential phenomena with which we have been made acquainted in the striped muscular fibres are repeated in the unstriped variety. They exhibit an electrical antagonism of the longitudinal surface and the tranverse section (§ 226); although it is somewhat weaker. They sometimes present zigzags when cut through (§ 1272); although this form is less frequently remarked in them than in the striped fibres. They undergo a *rigor mortis* (§ 1266) as the intermediate link between the departure of the vital functions and the access of vigorous putrefaction. Finally, their contraction is also immediately excited by two causes; by stimulation of the nerves, or of the muscular substance itself.

1296. The strong muscles of the alimentary canal, the urinary bladder, and the internal female organs of most mammalia, easily contract under the influence of artificial irritation. But many other parts in which microscopic research recognizes unstriped muscular fibre only respond to more favourable conditions. Hence we shall commence by considering the above structures.

1297. In the striped fibres, total contraction is the rule, and vermicular movement the exception (§ 1291). But in the unstriped fibres of the alimentary canal, the bladder, the oviduct, the uterus, and the larger gland-ducts, the reverse of this obtains. On looking at the small intestine of a recently killed rabbit, we chiefly remark an undulation (*d a*, Fig. 76, p. 134), which passes onwards with more or less activity, and often recedes (§ 399). But it proceeds more slowly than that of the transverse fibres of the œsophagus: so as to offer a certain deliberate tenacity, such as distinguishes the action of unstriped muscular fibre generally.

1298. The urine which descends from the kidneys gradually distends the bladder. The walls of this viscus yield by reason of their elasticity (§ 938). When the phenomena are observed in a recently killed mammal, the volume of the bladder is seen to be greatly lessened by the evacuation of the urine. It finally forms a spherical mass, the walls of which are thicker than before, but still exhibit vermicular movements under the influence of the electro-magnetic apparatus. Hence the state of *rigor mortis* is not necessary to this maximum diminution of capacity. No doubt one chief cause of it is the elastic reaction due to the decrease

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of that tension which formerly opposed contraction. But it sometimes happens that the contracted and globular bladder subsequently appears collapsed and thinner in its coats. This change indicates a previous vital contraction of its fibres, followed by a relaxation. It therefore follows that the unstriped muscular structures are capable of maintaining a tonic contraction (§ 1247) during a considerable period of time.

1299. This capacity is still more evident in the intestinal canal. When a certain portion of this is compressed in a newly-killed rabbit, it frequently becomes constricted to the remarkable extent represented by *d e*, Fig. 76. More limited irritation, or smaller degrees of sensibility, give rise to smaller constrictions; which are sometimes mere furrows of one side of the tube. All these contractions usually continue a long time, and are but slowly effaced. And however active the vermicular movements of neighbouring parts, they remain undisturbed.

1300. On irritating the sciatic nerve (*a b*, Fig. 206, p. 368) of a prepared frog, the transverse stripes of its gastrocnemius (*c*) at once contract. Here the stimulus and the effect follow each other so quickly, that it would require the most delicate instruments to measure the time which intervenes. But when we irritate the alimentary canal or its nerves, a considerable interval often precedes the occurrence of contraction.

1301. The differences exhibited by the two kinds of muscular fibre may be best verified in those organs which possess striped fibres in one animal, and unstriped in another. The iris (*b*, Fig. 150, p. 273) contains striped fibres in birds; and unstriped in man and the mammalia. On bringing the eye of a pigeon into the circuit of an electro-magnetic apparatus, the size of its pupillary aperture (*c*, Fig. 150) is instantly changed. But when this experiment is repeated on a rabbit, the change is slow and gradual. And in the bird, it disappears when the operation ceases; while in the mammal, it may continue afterwards.

1302. The œsophagus of most domestic mammalia is chiefly composed of striped fibre; and that of birds, of the unstriped variety. Confining our attention to the phenomena presented by newly-killed animals after the destruction or removal of their medulla oblongata, we shall find that, under the influence of electric irritation, the œsophagus of mammalia contracts totally and instantaneously; and relaxes the moment it ceases. That of birds generally responds more slowly and locally, and retains the constrictions it has once acquired during a longer time. The same difference may often be seen in the œsophagus of many mammalia —such as the cat or horse,—in which a considerable layer of unstriped muscular fibres ascends from the stomach.

1303. The alimentary canal of man and most of the vertebrata contains unstriped fibres. Reichert found that, in the tench, (*Cyprinus tinca seu Tinca chrysites*) the walls of the stomach and intestine contain striped

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fibres. These parts contract with a sudden impulse. The intestine of the river cray-fish (*Astacus fluviatilis*), which also contains striped fibres, offers somewhat similar results.

1304. It is easy to see that these differences in the action of the two kind of fibres affect degree only. And there are many phenomena which show that, under peculiar collateral circumstances, even this distinction may altogether disappear.

It is true that the maximum velocity attained by the intestinal undulations of a rabbit never equals that of the vermicular movement of the œsophagus (§ 382). But, in some rare instances, the difference is much less than usual. And the action of the heart—which we have hitherto purposely abstained from considering, and to which we shall return in treating of the function of innervation—plainly proves that local and enduring contractions may occur in striped fibres. While there are special circumstances which cause an exception to the rule, that unstriped muscular substance only contracts a short time after irritation. By irritating the medulla oblongata, the cerebrum, or the cerebellum, the vermicular movement of the alimentary canal may be excited as quickly as that of the gastrocnemius on stimulating the sciatic nerve.

1305. The unstriped muscle usually responds to mechanical irritation of its substance with greater energy than the striped fibre; and often exhibits a more punctual obedience to such a stimulus than to an irritation of its free nerve-fibres. It is probable that its substance is capable of contracting without the intervention of the nerves (§ 1255). But the study of the cardiac movements will again show that many of these properties also belong to the striped fibre. In the ureter of the rabbit, the unstriped muscle sometimes does not respond to electrical irritations of its own substance: while, when these are applied to its nerves, active vermicular movements ensue.

1306. Structures having the same morphological characters as the unstriped fibre are found with the aid of the microscope in the bronchi, the vessels, many of the smaller gland-ducts, the spleen, and some portions of the external integument. But it is generally impossible to excite them to contraction by mechanical or electrical irritation. The rapid succession of electric shocks produced by the rotatory or the electro-magnetic machine is oftener, though not always, effectual. Under such circumstances, however, we obtain, not vermicular movements, but tonic constrictions; which remain some time after the cessation of the stimulus, and are then gradually effaced. These results are, no doubt, determined by peculiar collateral circumstances. We must recollect that the *cutis anserina*, the narrowing of the vessels, the wrinkling of the scrotum, and other similar phenomena which depend upon these fibres, only occur during life under peculiar conditions—such as depression

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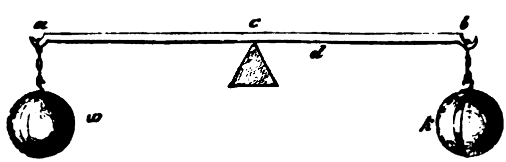
of temperature. We are therefore entitled to conjecture, that the chain of causation is made up of a series of links which are at present unknown.

1307. The behaviour of the alimentary canal also leads to the conclusion that the contraction of unstriped fibres depends upon many conditions which are not always present. The study of digestion has already taught us that the intestines rest at particular times, in spite of the irritations to which they may be subjected; while at others they become active under stimuli which are to all appearance similar.

1308. *General mechanical relations of the locomotive organs.*—The muscles are the active organs of movement, their contractility furnishing the mechanical force which produces changes of place. In order to this, they rule over certain passive organs of locomotion;—the bones, cartilages, ligaments, tendons, skin, and other parts with which they are connected. And since all these structures act as levers, which are moved by an exercise of force, we must first become acquainted with the physical laws which regulate the action of levers.

1309. Let us suppose that a rod—such as the beam of an ordinary scale *a b* (Fig. 222)—rests by its middle *c* on a solid support or fulcrum, while its two arms, *a c* and *c b*, possess the same length and

FIG. 222.



weight. Such a lever, being one of the first kind, will remain in a state of equipoise. If we hang a weight, *w*, at *a*, and a second, *k*, exactly equal to it at *b*, the equipoise will still be maintained. But if *k* is heavier than *w*, the arm *c b* descends, while *a c* and *w* are raised. This occurrence is commonly said to depend on the equality of the mechanical momenta. The product of the length of the arm of the lever *c b*, by the weight *k* slung vertically, is called the static or mechanical momentum. If $w \times a\,c = k \times c\,b$, we have a state of counterpoise. But if *k* be greater than *w*, and hence $w \times a\,c < k \times b\,c$, that arm of the lever which answers to the greater burden *k* will preponderate.

1310. But the latter result may be attained in a different way. If *c b* be greater than *a c*, while *w* and *k* remain equal, we also find $w \times a\,c < k \times b\,c$. Hence the preponderance may be determined by three circumstances:—by increase of the weight, elongation of the arm of the lever, or both. If *a c* be less than *b c*, and *w* greater than *k*, the differences may so compensate each other that $w \times a\,c = k \times b\,c$; and the counterpoise may still be maintained.

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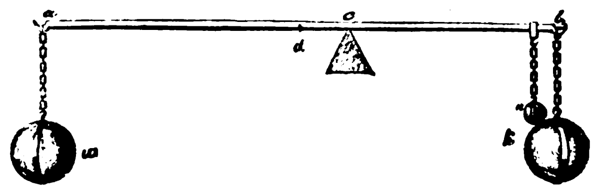
1311. Supposing that the lever $a\,b$ (Fig. 223) is poised exactly on its middle, d, and that its two arms $a\,d$ and $b\,d$ correspond in weight as well as length, its equilibrium will not be disturbed. But if they differ from each other—if, for instance, $a\,d$ is heavier than $d\,b$, or if the fulcrum be displaced from d to c, so that $a\,c$ is longer, and therefore heavier,

FIG. 223.

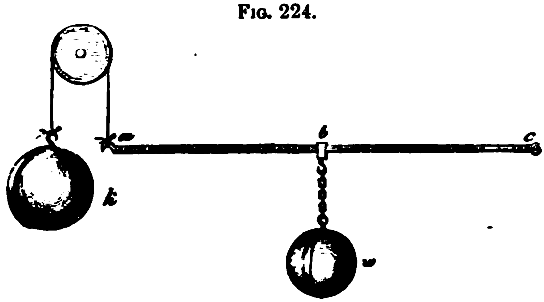


—there will be a certain preponderance of weight on this side. In this case the weight w suspended from the arm of the lever acts in common with the superfluous weight of the latter itself. Hence, in order to compensate this, a second or counterpoising weight n must be applied to the lever, $b\,c$. It is only when $n+k$ furnishes the same force as w that equilibrium is produced.

1312. This fact explains why we distinguish between the mathematical, and the real or material lever. The first constitutes that passive line of movement which is distinct from all material relations, and in which we have but to consider the length of the lever's arms. While as regards the second or real lever, we must be closely acquainted with its material relations, and must estimate the weight of its several segments, before we can determine the conditions which cause equilibrium or displacement.

1313. The action of the one-armed lever may be easily deduced from what has been mentioned above. Let us suppose that $a\,c$ (Fig. 224) is

FIG. 224.



a mathematical lever, having its fulcrum at c, sustaining a certain weight w at b, and a counterpoise or a force at k. This is essentially a lever having two arms which partially coincide. The arm which sustains the weight corresponds to $b\,c$, and that acted upon by the force to $a\,c$. If

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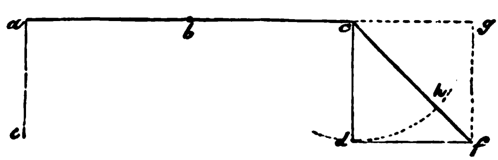
we assume $w=k$, we find $w \times b\,c < k \times a\,c$, because $a\,c > b\,c$. Hence to produce equilibrium, we must have $k \times a\,c = w \times b\,c$, consequently $k = w\frac{b\,c}{a\,c}$: *i.e.*, the longer its arm of the lever, the smaller may be the force k. Supposing $b\,c$ to be 2 feet, $a\,c$ 4 feet, and w 10 pounds, k need only amount to 5 pounds, since $5 \times 4 = 2 \times 10$. Thus lengthening the arm of the mathematical lever diminishes the force necessary to counterpoise in exactly the same proportion. Such an arrangement, in which the advantage turns in favour of force, is called a lever of the second kind.

In a lever of the third kind these circumstances are reversed. Here k forms the weight, which has to be moved by a force acting at b. Hence we lose an amount of force that corresponds to the shortening of the arm to which it is applied.

1314. When the lever ($a\,c$, Fig. 224) remains horizontal (§ 1315), the masses hitherto represented as the weights and powers act by their gravity; *i.e.*, perpendicularly. Hence $w\,b\,c$ forms an angle of 90°. But where, on the contrary, a force impinges obliquely upon its arm of the lever, part of its effect is lost.

The amount of such a force may be represented in the form of a straight line. Supposing it $= c\,f$ for the horizontal arm of the lever $b\,c$ (Fig. 225)

FIG. 225.



it will not effect more than the perpendicular $c\,d$, the length of which is determined by the line $d\,f$, parallel to $b\,c$. If we now describe an arc which has c for its centre, and $c\,d$ as its radius, it will be evident that $c\,f$ loses an amount equal to $h\,f$. We also see that the disadvantage must increase as the line approaches to $b\,c$ or $c\,g$; and must diminish as it nears $c\,d$.

1315. We shall shortly mention reasons which entitle us to assume that those attractive forces of the earth which produce the phenomena of weight, and the fall of bodies, are united in its centre. If we represent our planet under the scarcely accurate form of a perfect sphere, a body at d will be attracted in the direction of the radius $d\,e$, and one at i in that of $i\,e$. But the several molecules of every mass of moderate size lie so closely to each other that we may without perceptible error regard the corresponding spherical surface $d\,i$ as a plane tangent to it, and the radii $d\,e$ and $i\,e$, as parallels which are perpendicular to $d\,i$. Hence we say that the molecules of a body are attracted perpendicularly downwards towards the ground.

1316. The innumerable parallel actions of gravitation which result

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from the equally infinite number of the smallest atoms may all be regarded as united into one point; which is the common centre of them all. Hence this is generally called the centre of gravity. And the straight line which connects it with the centre of the earth is called the line of gravity. This will therefore cut the horizontal surface of the ground at a right angle.

1317. A sphere *a d b c* (Fig. 226), has its centre of gravity at *e*, and its line of gravity in that diameter *d c*, which being produced would meet the centre of the earth. The centre of gravity of every symmetrical body—for example, that of a regular ellipsoid A B C D (Fig. 227)—must lie in some part of the median line C D, since all the corresponding

FIG. 226.

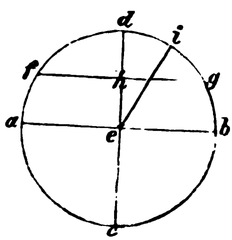
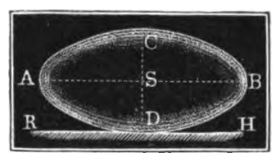


FIG. 227.



molecules on each side offer equal mechanical momenta (§ 1309). If the mass be also longitudinally symmetrical, this point will occupy the centre S, of the median axis C D. But if, on the contrary, it be arranged asymmetrically, its centre of gravity will occupy some place dependent on the form of the whole.

1318. In order that a body should remain at rest, its line of gravity must meet its surface of support. When it drops beyond this, the mass falls towards that side on which the line of gravity cuts the horizontal surface of the ground at an angle of 90°. Many attitudes of the human body are thus easily explained.

1319. Setting aside the subordinate influence exerted by many asymmetrical organs—such as the liver, the spleen, the pancreas—the human body consists of parts which are almost uniformly repeated on both sides. Hence so long as the distribution of these masses is not rendered unequal by any special movement,—such as extension of the hand,—the centre of gravity will occupy its median line. Accurate research further shows, that the centre of gravity of a healthy adult lying in the horizontal position occupies a transverse plane which cuts horizontally through the last lumbar vertebra. It is thus placed somewhat higher than *k* (Fig. 231, p. 394). While in the newborn infant it lies considerably higher; between the navel and the lowest part of the sternum (*c*, Fig. 231).

1320. Let us imagine that the man represented in Fig. 228 stands upright on a horizontal surface; without any burden, and with a sym-

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metrical disposition of his limbs. If the centre of gravity is at G, the line of gravity will descend on $G G'$. It thus strikes upon some point of that surface of support which is furnished by the soles of the feet. And so long as this condition is satisfied, the man cannot fall.

FIG. 228.

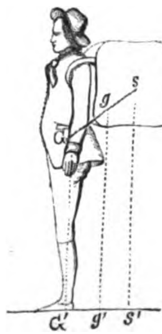

FIG. 229.

Let us now suppose his back to be burdened with a heavy pack having a centre of gravity at s, Fig. 228. This burden alone would have the line of gravity $s\,s'$; and would therefore stand safely on the horizontal ground. But when it hangs on the back of the man while he is standing upright, the centre of gravity common to both is shifted further backwards; namely, from G to g. Hence the line of gravity $g\,g'$ falls upon the ground beyond the surface which supports the soles of his feet. The man will therefore be pulled backwards. But if he bows the upper part of his body as represented in Fig. 229, the common centre of gravity g is placed further forwards. And since $g\,g'$ descends within the surface limited by his feet, the man remains standing.

1321. Just as a person carrying a burden on his back necessarily bends the upper part of his body forwards, so when he carries a considerable weight before him in his hands, he will incline himself backwards. Women advanced in pregnancy assume a similar attitude, because the anterior and lower part of the belly contains the enlarged uterus, the membranes of the ovum, and the fœtus; forming in all a weight of about 11 pounds. And mechanical considerations teach that a man ascending a steep path must act as if he carried a burden on his back;—that is, he must incline the upper part of his body forwards. While when we hasten down hill, it is as if we had a propulsive weight hung in front: so that we extend the trunk backwards. The lateral curvatures produced by carrying burdens on one side, together with the somewhat oblique attitudes of men who have lost the greater part of one arm, are also explained by the same laws.

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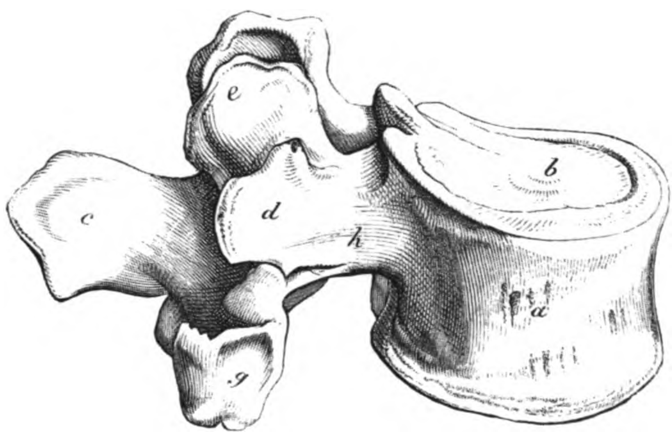
1322. Passing on to the arrangement of the skeleton, we find that the body (*a*, Fig. 230) of each vertebra offers a broad surface of support (*b*) —a kind of block. The laminæ (*h*) form rings which enclose the spinal marrow and its membranes. The different processes — such as the spinous process (*c*), the transverse process (*d*), and the oblique or articular processes (*e* and *g*)—complete the whole, and serve for the attachment of muscles. And some of them compose the joints on which the mobility of the vertebral column chiefly depends.

FIG. 230.



1323. These vertebræ,—which may be divided according to their various forms and situations into cervical (*b*, Fig. 231), dorsal (*d*), lumbar, sacral, and coccygeal,—are piled one upon another like a series of discs. In this way they form the rod of the vertebral column, which is somewhat curved, and is moveable within certain limits. Under the most favourable circumstances, the head (*a*, Fig. 231) is self-poised upon the atlas, or uppermost cervical vertebra. But it frequently loses its equilibrium, and tends to fall forwards. This tendency is checked by the action of the cervical muscles. In old age these contractile tissues become weakened; so that the head often falls forwards.

1324. The vertebral column (*b d*, Fig. 231) is wedged into the pelvis (*k*). This therefore forms a kind of basis of support, upon which the trunk can rest upright in the sitting attitude. But when a man stands upright, the legs (*l m s*),—which sustain the pelvis, and hence the trunk also,—form two columns, in the interval of which the line of gravity descends.

1325. The thorax or chest (*c*), which is composed of the ribs and sternum, is suspended in front of the vertebral column. It and its contents together form a burden which tends to flex the dorsal part of

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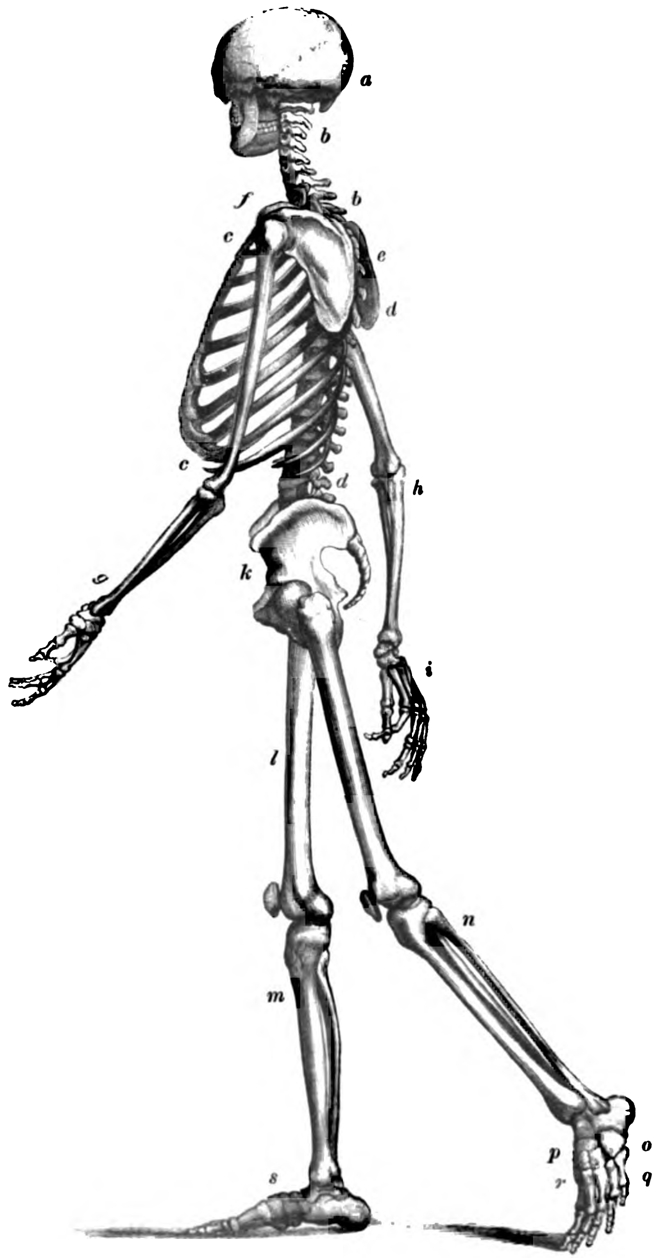
the vertebral column (*d*). In old age the relaxation of the soft tissues often leads to a curvature of this part.

FIG. 231.



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1326. The arms ($g\ h\ i$) hang like two weights from the upper part of the trunk. Hence when placed symmetrically, they will not affect the lateral equilibrium. But if one upper extremity be brought into a different situation from the other, the distribution of the masses is altered, and their centre of gravity changes its situation. Upon these circumstances depend the alternate movement of the arms in walking or running, in passing along a narrow path, or a tight-rope, or in any other feat of balancing.

1327. We have already learned the advantages of the peculiar arrangement of the osseous substance (§ 62). The other characters of the skeleton are adapted to its special requirements with equal nicety. This may be illustrated by a few examples.

1328. Bones which are destined to enclose other parts—such as those of the skull (a, Fig. 231), thorax (c), and pelvis (k), are generally flat: while those in which the circumstances better correspond with a columnar form—such as most of the segments of the arm ($g\ h\ i$), and the leg ($l\ m\ n$)—exhibit a more circular transverse section. The flatness of the shoulder-blade (e) is connected with the peculiar mechanism of the movement of the arm.

1329. The mobility possessed by numerous pieces is the chief reason why the skeleton consists of so great a number of bones. That of the adult consists of 218 pieces, besides the six small bones of the ear and the 32 teeth. Most of them are articulated with each other, so as to allow of considerable mutual movements. While many—such as the sternum, the bones of the pelvis, and tarsus,—are intimately united by tissues which only permit a very small amount of gliding movement. The sutures (above d, Fig. 66, p. 122) by which the numerous bones of the skull fit into each other only allow still smaller displacements. This is also the case with the teeth, which are fixed like nails into the cavities of the jaw. But all these modes of union have the advantage of permitting slight movements, which mitigate shocks, and thus assist to ward off the danger of fracture.

1330. The enlargement of many bones in the neighbourhood of joints not only increases their articular surface, but with this, the arc of their possible movement. And the tubercles and other eminences here met with often elongate the arm of a lever on which the muscles act. Assuming that the lowest of the two bones represented in Fig. 232 rotates around a centre at c, a muscle attached at d would act upon the arm of the lever $c\ d$. But if we now add the protuberance $f\ e\ g$, the force will be enabled to use the longer arm $c\ e$. In this way the common extensor tendon g (Fig. 233) of the leg is attached to the patella h; and the ligamentum patellæ i which comes off from this is fixed to the tuberosity of the tibia (m, Fig. 231, p. 394). Hence the arm of the lever $h\ f$, which is acted upon by the extensor tendon of the

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leg, has more favourable mechanical relations than if the tuberosity of the tibia *f* were absent.

FIG. 232.

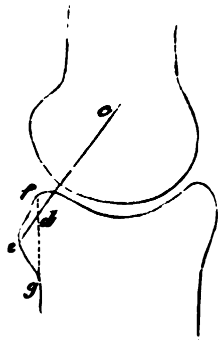
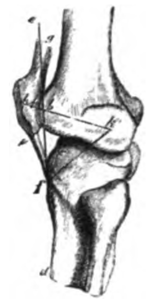


FIG. 233.



1331. The convex or concave parts of the bones furnish extensive surfaces, which are capable of giving attachment to a larger number of muscles. We shall hereafter see that, other circumstances being equal, the strength of the muscles increases with the number of their fibres. Hence they are thus rendered capable of effecting a more powerful traction.

1332. The hardness and roughness of the osseous substance render it necessary that its articular surfaces should be provided with proper coverings, such as cartilage and other dense tissues. Where requisite, fat and solid fibrous discs are interposed, so as to form elastic cushions. The whole joint is intimately united by means of ligaments. We have already seen (§ 886) that the synovia furnished by the synovial membrane fills the superfluous space, and diminishes the amount of friction (§ 80). And the way in which the external atmospheric pressure diminishes the burden of the joints has also been (§ 96) explained.

1333. The various joints exhibit very different degrees of mobility. The cartilages which are interposed between the vertebræ (as shown by the median longitudinal section in Fig. 234) contain fibrous layers, which may be bent or stretched according to the attitude. When the bodies of the vertebræ *a* and *b* meet anteriorly, so that the corresponding part of the vertebral column becomes concave, *f* and *g* are folded inwards, while *i* and *k* are put upon the stretch. While bending the vertebræ backwards will give rise to the contrary result.

1334. Many of the more perfect joints, such as those of the articular processes (*e* and *g*, Fig. 230, p. 393), only allow of slight gliding movements, and very limited rolling ones. Others are essentially hinges, which allow of movement in but one direction;—such as obtains in the flexion and extension of the fingers. A similarly limited function also

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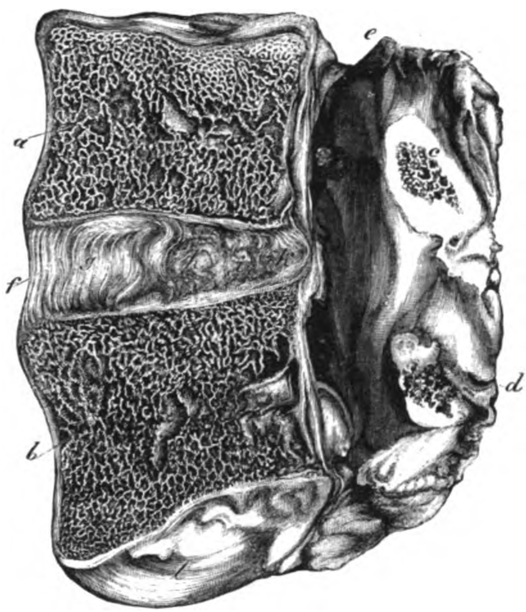
occurs in the elbow-joint; and under certain circumstances, in the knee. The former exhibits the further peculiarity that the olecranon process (*c*, Fig. 240) is locked into a depression of the humerus (*a*); so that, even in extreme extension, the upper and fore-arm can only form a straight line.

FIG. 234.



1335. The enarthrodial joints, such as those of the hip and shoulder, allow a very free movement. The spherical head of the femur (*g*, Fig. 11, p. 35) rotates through a considerable arch in the acetabulum (*i*). The head of the humerus (*f*, Fig. 235) plays even more freely in the shoulder-joint.

FIG. 235.

1336. A dislocation is produced by the rupture of part of the soft tissues of a joint, so that the head of the bone emerges, and is driven into some other place; both by the blow which produced the injury, and by the tractile force of the muscles (§ 1071). The operation of reduction is an attempt to restore it to its previous position.

1337. Most of the powerful muscles are not immediately attached to the passive organs of locomotion over which they preside, but are connected with them by intervening tendons. We have already (§ 61) seen that the substance of these is endowed with all the qualities necessary for such cords.

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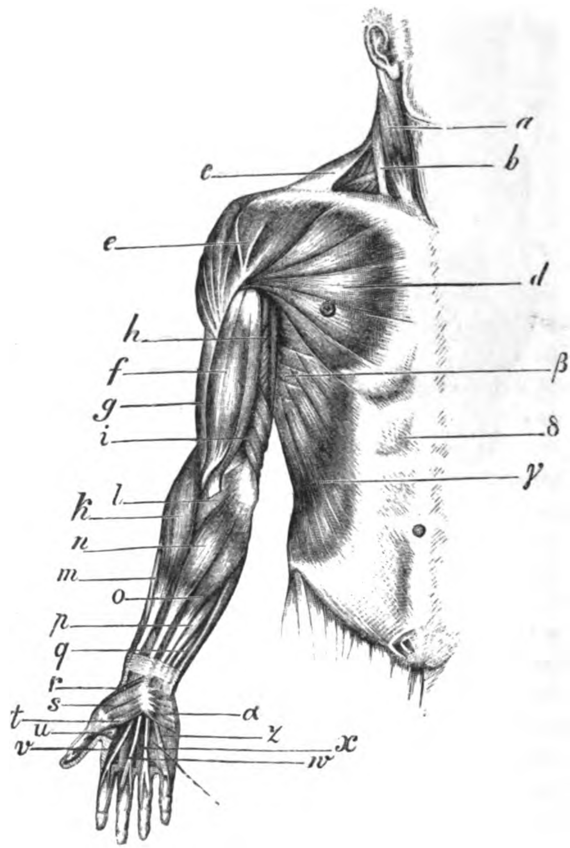
1338. The end of each muscular fibre is connected with a **smaller** tendinous bundle. Hence the entire transverse section of the **tendon** is much smaller than that of the muscle. This secures the **advantage** of a smaller surface of attachment, and therefore of a smaller **size** of bone. In this way the biceps muscle of the arm (*f*, Fig. 236) **con-**

FIG. 236.



verges to the small tendon seen in the figure. This circumstance, together with the double action of which the muscles are capable, explains why they are often provided with tendons at both ends.

1339. With this is often associated another advantage, which may also be illustrated by Fig. 236. Powerful flexion of the finger demands strong muscles. But these could not be applied to the fingers or the hands without rendering such parts disproportionately large, and unfit for their more delicate functions. Hence nature removes the contractile tissues to the fore-arm, and conducts them downwards as the white cords

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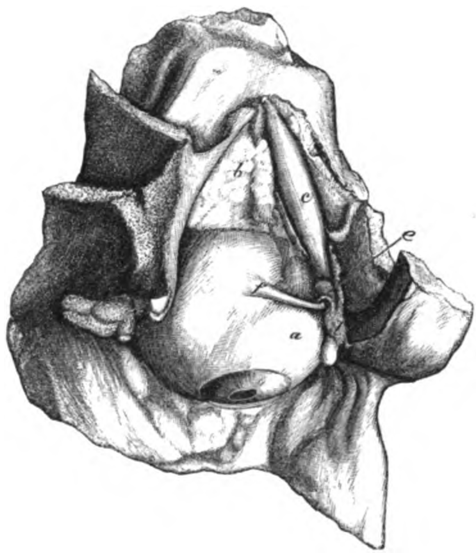
or tendons depicted in Fig. 236. Both the usefulness and beauty of many parts of the body depend upon similar arrangements.

1340. We have already found (§ 850) that the tendons have special sheaths, which allow them to glide to and fro without much loss of power. But since the muscles cannot always be applied in the directions in which their tendons are intended to act, other structures are often interposed as pulleys. A fatty cushion (*b*, Fig. 237) effects this change of direction

FIG. 237.



for the straight muscles of the eye. While the tendon of its superior oblique muscle *c* passes through a cartilaginous pulley *e*, in order that the action of its muscle in the direction of *c e* may draw it in that of *f e*.

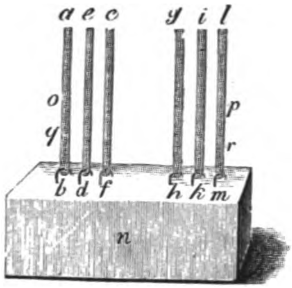
1341. The force exerted by the muscles at the instant of their contraction will of course vary with the state of their nutrition, and the amount of stimulus which they at the moment obey. But since many muscles are attached obliquely to their tendons, and these are not fixed at right angles to their bones, a certain quantity of force will be lost (§ 1314). Hence the work really effected must be less than that performed by the muscles themselves.

1342. The diagram at Fig. 238 may serve to illustrate the chief circumstances here concerned. In this figure, *a b*, *e d*, *c f*, *g h*, &c. represent the straight fibres of a muscle; while *a e*, *e c*, *g i*, *i l*, are the small intervals between the several fibres, and *c g* those between the bundles of fibres. Both are filled by areolar tissue (§ 448), which in no way contributes to the muscular contractions.

1343. Every isolated muscle exhibits a natural length, which corre-

sponds to its elasticity. But if it be suspended above, and laden below with the weight n, the elastic resistance of its fibres will be overcome, and they will be extended to a certain amount. The lengths of this artificial extension, $a\,b$, $e\,d$, &c., will exceed the natural, $a\,q$, $l\,r$, by a certain amount.

FIG. 238.



1344. When the muscle laden with n contracts to $o\,p$, the diminution of its length amounts to $o\,b$; or, compared with its former extension, to $o\,b \div a\,b$. But the weight n is raised to this height, $o\,b$. Hence the height to which a weight is raised would express the diminution in the length of any contracting muscle which consisted of straight fibres.

1345. If we suppose that the whole of the muscular fibre $a\,b$ consists of particles having an equal activity, the height of elevation will be directly proportionate to the length of the fibres. If a fibre which is two inches long contracts to half this length, we get an elevation of one inch. But, other circumstances being equal, this would amount to two inches for four inches of extended length. Hence we say that the amount of contraction of a muscular fibre depends upon its length.

1346. At the instant of contraction every cylindrical filament of a muscular fibre developes a certain force, corresponding to a definite load. This force will necessarily increase with the number of filaments contained in each fibre. If we imagine two muscles to contain the same proportion of areolar tissue, and fibres of equal thickness, the number of these latter will be proportionate to the transverse sections $a\,l$, $q\,r$, $b\,m$, (Fig. 238). Hence the forces excited by corresponding degrees of contraction are proportional to their transverse sections. We may therefore refer our estimates of force to some unit of transverse section: as, for instance, a square inch.

1347. The effective action of a muscle is due to two causes; the amount by which it is shortened in a given time, and the force which is then developed. The product of both these, reduced to an unit of time, is the mechanical momentum or dynamic unit; and it therefore forms a quantity which is a function of these two elements. For example, if a muscle four inches long contracts to half this length in one second of time, and raises a pound for each square inch of its transverse section, we have an effective action of $2 \times 1 = 2$ pounds, for one second of time, and one square inch of transverse section.

1348. The shortening is a function of the length, the force is similarly related to the transverse section, and the effective action is the product of both these magnitudes. But since the volume of a body is the product

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of its length by its mean transverse section, it follows that the effect is proportional to the capacity. If the specific gravity is constant, the weights vary with the volumes. Supposing this to be the case with the muscles, other circumstances being equal, the effects will correspond to the weights. The general theory may therefore be thus stated:—the length of the fibres determines the amount of shortening; the transverse section of the muscle, the force; and the weight or volume, the effective action.

1349. But the actual occurrences are far from offering an exact correspondence with the suppositions upon which this statement is based. In the first place, it may be questioned whether one part of a longitudinal filament (*a b*, Fig. 238) always shortens as much as another. Under low powers of the microscope it may frequently be seen that, with heavy burdens, this is not the case. This renders the amount of shortening a variable quantity, from which no simple relation to length can be deduced. Even comparing the different effects of one and the same muscle, the number of fibres in an unit of its transverse section—the fundamental condition of the force—will only remain unaltered when their watery contents, their extension, and their form, are unchanged, And comparing different muscles with each other, we meet with important original differences. One muscle has a larger proportion of areolar tissue than another. Its several fibres do not always exhibit the same thickness: a condition which may again give rise to differences in the relative quantity of its surrounding tissues. And since the given transverse sections diminish with the extension, we have here a new source of difference. Indeed it is possible that this circumstance may interfere still more actively. Supposing every molecule of the transverse section of a fibre to exhibit the same amount of force, this would vary directly as the square of the diameter. But it may be questioned whether the fibres are not so constructed, that the forces of their peripheric atoms differ from those of their central ones; while the relative number of both differs with the diameter of the fibres. In this case a transverse section of the same muscle would include dynamic agents of unequal value. And equal transverse sections of two different muscles always form unequal magnitudes, which cannot be directly compared with each other.

1350. Hitherto we have supposed that the muscular fibres take a direct and parallel course (*a b*, *c d*, &c. Fig. 238), and are acted upon by the weight (*n*) at right angles. But when, on the contrary, they are attached obliquely to their tendinous substance, *f b c*, like *b d* and *e* (Fig. 239), they everywhere form variable quantities, the values of which defy calculation. Under such circumstances the degree of elevation from *c* is only a part of the true diminution in length, and of the force really developed by *b d* and *e* (§ 1314). Since the several fibres of almost all muscles exhibit unequal lengths, and unequal angles of attachment, the most

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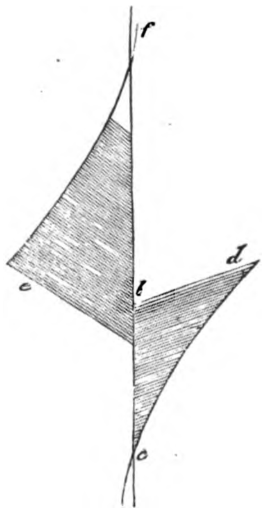
careful research can only furnish vague averages. While a longitudinal or transverse unit of such a mass of muscle allows no definite comparison with a similar unit of a muscle composed of straight fibres.

FIG. 239.



1351. In practically working out such experiments, we are met by new difficulties. Since the action of a muscle may vary between a minimum which may be regarded as =0, and a maximum, our first object is to determine the value of the latter. But this depends, not merely on the nature and amount of the stimulus applied to the muscle, but also on the degree of its susceptibility, and on the molecular constitution of the particular muscle. Hence we can never reckon upon any maximum which might not be exceeded by the results of other and more favourable circumstances.

1352. In making such an attempt with the entire limb of an animal, many circumstances render it impossible to calculate the result. Such are the number of the muscles, the positive and negative amounts of the antagonist contractile masses, the oblique attachment of the muscular and tendinous fibres, and finally, the changeable phenomena of their leverage. On these grounds, even the simplest investigation of this kind, —which concerns only the flexors of the head, the flexors or extensors of the finger or toes, or the muscles of the calf of the leg,—is utterly unsatisfactory. While when we experiment on an isolated (and straight-fibred) muscle of a frog,—which owing to its tenacity of irritability is preferable to that of a mammal (§ 1261),—there is little doubt that its action is diminished by the previous wound, by the gradual death of the muscle, by the evaporation from its surface, and perhaps also by the abnormal influence of the air. Besides this we shall hereafter see that even weights not merely extend the muscle, but are also able to withdraw a certain amount of its vital activity.

1353. Hence all these observations can only prove certain general propositions. Their details merely serve as illustrations, and not as definite numbers to which any higher significance may be ascribed.

1354. The hyoglossus of the frog, and some of its femoral muscles, —such as the sartorius—offer the advantage of having muscular fibres which are straight and parallel in at least the greater part of their course. Hence there is no need of correcting their results by any hypothetical calculations. When laden with a small weight — such as half a drachm — they sometimes contract under the influence of the electro-

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magnetic machine so powerfully, that their length is lessened by more than $\frac{3}{4}$ths or $\frac{4}{5}$ths. The formation of zigzags (§ 1272) does not render this great amount of contraction impossible. An excised muscle, the length of which has been diminished more than one half by these elastic foldings (§ 1273), may lose an additional fourth under the influence of the galvanic current. Now since the fibres become straight during contraction (§ 1275), it follows that the shortening here amounts to $\frac{3}{4}$ths of the original length.

1355. Most of the living muscles are incapable of contracting to their maximum; since, prior to this, they are checked by the levers on which they act. It is only some of those which surround tubes,—such as the pharynx and œsophagus (*g* to *s*, Fig. 71, p. 127) or the sphincter ani,—which are more favourably situated in this respect.

1356. The amount of contraction effected by a muscle generally decreases with the increase of the weight by which it is laden. A hyoglossus muscle which contracted an inch under a burden of 31 grains, contracted but ·72 inches under one five times as heavy, and only ·063 under 10 times, ·024 under 15 times, and ·004 under 25 times, the first weight. Hence a maximum of burden permits but a minimum of shortening.

1357. Alteration of the weights may operate in two ways. The heavier weight obviously elongates the mass of muscle. The extension (§ 1343) of the hyoglossus adduced as an example amounted to 1·33 inches with 31 grains; and to 1·59 with 5 times, 1·75 with 15 times, and 1·99 with 30 times, this weight. Hence the degree of shortening (§ 1344) is determined by the amount of extension and of contraction; or by the stretching, the elasticity, and the vital contraction. In addition to this, much of the susceptibility is destroyed by too heavy a burden. If a heavy weight be allowed to fall on the scale represented in Fig. 218, (p. 380), so that the rapidity of its descent increases its force of traction (§ 66), the contractility of the most vigorous muscle may be annihilated at once and for ever.

1358. The amounts of force may be considered under two forms: viz., the force of counterpoise, and the maximum force. By reducing both to units of transverse section, we may perhaps compare the corresponding numbers offered by the same kind of muscle.

1359. Let us suppose that *a q*, Fig. 238, is the natural and original length of the muscular fibre when laden with no weight,—when the weight *n* elongates it to *a b*, the increase *q b* is due to extension. If the muscle then contracts to the length *a q*, it is obvious that the shortening has removed the extension. Now the muscles become more elongated, and less shortened, the greater the forces of traction which are applied. The force of counterpoise is determined by the weight which extends the quiescent muscle just as much as it contracts under

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the influence of its vital activity. This mode of regarding the action of force was originally introduced by Edward Weber.

1360. In this way the hyoglossus of a frog exhibited 4lbs. $3\frac{1}{2}$ oz. for $\frac{2}{13}$ths of a square inch of transverse section, and 39 per cent as the amount of shortening; the sartorius, 2 lbs. $6\frac{1}{2}$ oz., and 18·4 per cent; and finally the gastrocnemius, the fibres of which pass obliquely (Fig. 239), 2 lbs. 10 oz., and 10·4 per cent. Hence we see that the force of counterpoise increases as the corresponding length of extension decreases. These relations are explained by the disturbing effects of the latter. The burden which produced the state of counterpoise was from 30 to 32 times as great as the weight of the hyoglossus or sartorius: and 47 times as great as that of the gastrocnemius.

1361. It results from the examples already adduced (§ 1356), that the weight and the amount of shortening have no simple inverse ratio to each other. The former may be greatly increased, while the latter is less decreased. Enormous weights still allow of minute contractions. So that, by taking a minimum of shortening, we get a corresponding maximum of force. Where the former is so small that it may be dismissed without any appreciable error, it presents this advantage:—that the force need not be previously reduced to an uncertain transverse section, but to units of weight; so that it can be directly compared with the weight of the active muscle.

1362. We may assume ·004 inches to be the minimum contraction of the frog's muscle made use of in such experiments,—an estimate which is equivalent to about $\frac{1}{6}$th—$\frac{1}{3}$rd per cent of its length. Under the most favourable circumstances it was found that a square line of the hyoglossus overcame a weight of 2427·3, and the same unit of sartorius 3874·1, grains. In the first case, the weight raised amounted to 1092 times as much as the muscular mass, and 1216 times in the last. Under the most favourable circumstances, the gastrocnemius raised more than 2800 times its own weight. And if we consider that such powerful traction greatly damages the irritability of the muscles, especially of those with straight fibres, it will follow that even these extraordinary quantities are rather too small than too large.

1363. Other observations will but confirm this conclusion. Thus, if we make use of an apparatus[40]) in which the artificial extension produced by the weight is avoided, and the frog's gastrocnemius is allowed to act with its natural mode of attachment, we find that it can raise from 16 to 17 thousand times its own weight through a minute distance. Here a square line of transverse section corresponds to from $4\frac{1}{3}$rd to $5\frac{1}{7}$th pounds, and from ·1 to ·3 per cent of shortening. And since these muscles were separated from the rest of the animal's body, it is probable that their effect was always less than what they would have accomplished in the living animal.

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1364. If the amounts of shortening and the weights had a simple inverse proportion to each other, the effective action (§ 1347) would always remain the same. But we have already seen (§ 1361) that the weights increase more than the lengths decrease. It is true that a muscle which only sustains small weights contracts more strongly. But the greater decrease of length is incapable of compensating the diminution of weight beyond a certain limit. Hence the maximum of effective action will coincide, neither with that of the shortening, nor with that of the weight, but with a certain mean of both. For instance, the hyoglossus of a frog exhibited the following results :—

Weights in grains.	Extension in inches.	Elevation in inches.	Effect in grains to an inch.
30·89	1·33	1·02	202·4
154·44	1·59	·72	717·9
308·88	1·75	·063	125·5
463·32	1·87	·024	70·6
617·76	1·91	·012	47·1
772·20	1·95	·078	39·2
926·64	1·99	·039	23·5

So that the maximum of effect coincides, neither with the maximum contraction of 1·02 inches, nor yet with the maximum weight of 926 grains, but with one of the intervening observations, which offers a weight of 154 grains, and a height of ·72 inch. At the same time we see that the heaviest weights give the smallest results when reduced to a dynamic unit.

1365. The same conclusions may be deduced from our own actions. It is true that we can raise a heavy weight through a small space during a short time; but fatigue renders it impossible to continue or repeat such a task. In order to use the muscular force of an animal most effectively, we select moderate weights, such as will not produce too great exhaustion. This not only enables us to obtain the greatest dynamic effect, but also allows of the action being prolonged for many days with out permanent exhaustion.

1366. Under abnormal circumstances, the convulsive contraction of muscles sometimes ruptures the strongest tendons (§ 50). And even ordinary muscular actions presuppose very considerable force. But the effects accomplished are far short of the maxima which we have found in the dead muscles (§ 1362, *et seq.*). This difference depends upon two causes. Even the contraction made use of to overcome heavy weights never rises to the artificial maxima which are produced by the rapid shocks of the electro-magnetic machine; for these would exhaust irritability much too rapidly. Besides this, most muscles act under circumstances which waste a good deal of their power (§ 1314) in obliquity of attachment, or in unfavorable leverage.

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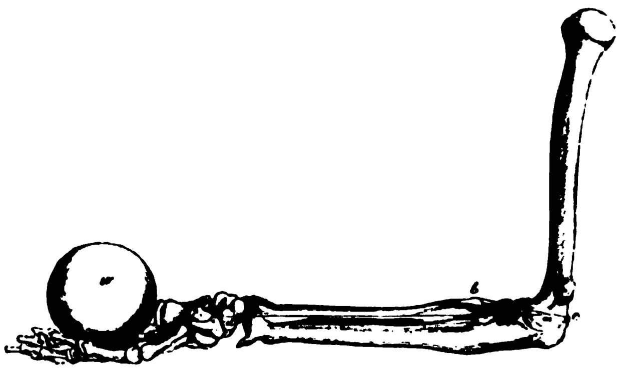
1367. Both the shapeliness and use of the muscles require many of the fibres to be fixed obliquely to their tendons or aponeuroses. This statement also applies to the attachment of tendons to the bones and other passive organs of locomotion. And not only is a great amount of force thus lost, but, for obvious reasons, unfavourable leverages are selected.

1368. We have seen (§ 1313) that levers of the third kind—in which the force acts upon the shorter, and the weight upon the longer, arm—imply the greatest exertion of force; while those of the second kind—in which the contrary obtains—require much less. It might thence be supposed

FIG. 240.



that Nature would everywhere make use of this latter advantage. But an examination of the organs of locomotion will show that the levers in which force is thus favoured occur less frequently than those in which it meets with greater difficulties. The reason of this will be evident from the study of a single example.

The centre of gravity of the fore-arm and extended hand lies at about $\frac{5}{8}$ths of the distance from the elbow-joint towards the point of the middle finger. But let us suppose that a man holds a weight (*w*, Fig. 240) in his flattened hand. The centre of gravity common to the weight, the hand, and the fore-arm, then lies at *d;* so that when the fore-arm moves upon the lower end of the humerus in the elbow-joint, around the centre *a*, that arm of the lever which corresponds to the weight (§ 1313) amounts to *d a*. But the tendon of the biceps muscle (*f*, Fig. 236, p. 398) which bends (and, in our example, raises,) the fore-arm is attached at *b:* so that the shorter arm of the lever, *a b*, corresponds to the force. Hence the effect is reduced to the quotient of *a b* divided by *a d* (§ 1313).

1369. The diagram (Fig. 241) will at once explain the reason of this. In the first place, if the muscles or the force belonged to the longer arm

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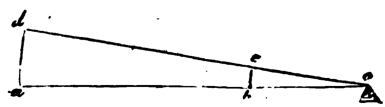
a c, and the passive organs of locomotion or the weight to the shorter one *b c*, very unsuitable forms and arrangements would result. And since the arc produced by the contraction of muscles is determined by the shortening of their fibres, they would have to contract to an amount

FIG. 241.



corresponding with the longer line *a d*, in order that the centre of gravity of the weight should describe the smaller arc *b c*. Hence nature selects this kind of lever when the circumstance just mentioned allows force to be economized without any disadvantage. But as this is not usually the case, the arm *b e* is made that of the power; with an obvious waste of a certain amount of muscular force. The quantity of this (§ 1363) is, however, amply sufficient to sustain the loss. So that a muscular contraction which only amounts to *b e*, can thus give rise to the more extensive movement *a d*.

1370. From all this it is evident, that the muscular fibres contain a substance which, at the instant of its shortening, furnishes a powerful tractile force. Hence large quantities of force may be sacrificed to the perfection of a particular arrangement without destroying its efficiency as an apparatus of motion.

1371. *General Movements of Man.*—We have already seen that the cervical muscles are generally required to keep the head upright (§ 1335); and the dorsal, to preserve the extension of the back (§ 1325). Their aid also suffices to the sitting posture, in which the pelvis furnishes the immediate basis of support. But that of standing requires additional muscular actions. The legs consist of a series of pieces united to each other; and hence they bend of themselves when any weight is placed upon them. The large glutei muscles, which occupy the outside of the pelvis (*k*, Fig. 231, p. 394) must therefore contract, to prevent rotation at the hip-joint; and the extensors of the leg (§ 1330), to hinder flexion at the knee. And as the leg (*m*, Fig. 231) cannot be spontaneously retained perpendicular to the foot (*s*, Fig. 231), muscles are applied here also to secure the necessary solidity. This explains why a person whose muscles are exhausted by fatigue, or paralyzed by abnormal influences, falls together in a heap when the support of the body is thrown upon his lower extremities. The dead body will obviously present similar phenomena.

1372. The surface limited by the two soles of the feet forms the basis of support of the human body in the standing posture. Consequently

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the body only falls, when the perpendicular line of gravity (§ 1316) drops beyond these limits (§ 1318). When a person raises one leg, the surface of support is diminished by more than half its breadth; since it now consists of the sole of one foot only, while it was formerly the surfaces of both feet, together with the variable space left between them. And, in order that he should not fall, he must bend the upper part of the trunk towards the side of that leg on which he stands; otherwise the unsupported half of the body preponderates, and pulls down the whole towards its side (§ 1320). And this change of posture must be carried so far, as to allow the common line of gravity to fall upon that limited surface of support which is furnished by the sole of one foot.

1373. These conditions are easily satisfied. Indeed, we shall soon find that the ability to walk and run depends upon such adjustments. But since the surface of support is extremely small, and the muscles which keep the active leg extended are laden with at least twice their former weight, the attitude of standing on one leg can only be maintained for a short time. Fatigue produces oscillations, which at first favour counterpoise, but afterwards falling.

1374. In a person possessing only one leg, we find a second disadvantage. When a man raises one of his two feet, he can hold the lower extremity in such a position, that the centre of gravity of the whole body is shifted but little upwards. But where the thigh has been amputated in the upper third of its length, the great loss of substance below this point has considerably raised the centre of gravity. Thus while in an entire corpse the horizontal plane of gravity falls between the navel and pubis, it is raised to the navel by the removal of one leg, and to the lower extremity of the sternum (*c*, Fig. 231, p. 394) by that of both. Hence in the upright attitude, the centre of gravity of the maimed person will be higher than that of the uninjured subject. But since, other circumstances being equal, a body falls over more easily, the further its centre of gravity is removed from the basis of support, a one-legged man will fall more easily than a person who is standing on one of his legs. The difficulty of preserving the attitude will vary with the shortness of the portion of limb which remains. And though, in spite of this, such persons are often able to stand alone for some time, still we must not forget how greatly habit assists them in discovering the necessary compensative attitudes of the upper part of the body.

1375. In man, progression chiefly depends upon a definite and alternate play of both legs; one of which is always sustaining the weight of the body, while the other is moved onwards. Hence the former is called the sustaining, and the latter the progressive or swinging limb. In the course of a complete or double step, both legs take up these functions alternately.

1376. Supposing the right lower extremity forms the column of sup-

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port, the pieces of bone which compose it will have the attitude represented by *l m s* (Fig. 231, p. 394); while the left, which has to swing, is placed further backwards. This now raises the greater part of its sole from the ground,—or as it is usually expressed, rolls it off,—and thus moves from somewhere about *s* to *o p q r*. It then impinges against the surface of support only by the toes and the ball of the foot, and thus acquires a greater length, which, although diminished by a simultaneous flexion of the knee-joint (over *n*), still always suffices to push the left half of the upper part of the body somewhat forward, while it allows the right to remain to a certain extent behind it. If the left leg, which hangs like a pendulum from the hip-joint, now swung forwards, its length would soon make it strike against the ground. Hence a flexion of the knee and hip-joints shortens its straight length. When it has completed its swing, it is extended so as to reach the ground, on which it treads by the entire sole of the foot, *s*, to take henceforth the part of the sustaining limb. But the arc through which it has swung has caused it to precede the other leg, so that the latter now forms the limb of progression.

1377. From the circumstances mentioned in § 1371, it follows that the sustaining extremity must be extended so as to form a column. The straight line formed by the thigh and leg (*l* and *m*, Fig. 231, p. 394), is inclined backwards so long as the progressive leg remains behind, and forwards after it has advanced. Its upright posture occurs in the middle of the swing of the advancing limb.

1378. If we consider the mode in which the upper part of the body is supported in the course of a double step, we shall find that it is successively sustained, (1.) by both legs with a gradual predominance of the first supporting leg; (2.) by the first supporting limb alone, while the second one swings; (3.) by both legs again; and (4.) by the second supporting leg, while the first steps forwards. But since both feet co-operate in the act of standing, 1 and 3 form the instants of standing, and 2 and 4 those of progression strictly so called. Hence, other circumstances being equal, a person will advance more slowly, the more 1 and 3 predominate. While if the times occupied by 1 and 3 are diminished almost to nothing, we get movements of progression which approximate to those of running.

1379. The velocity of progression may be diminished not merely by prolonging the times of standing, but also by other means. If, for instance, the progressive leg swings further forwards than where it is subsequently deposited on the ground, a certain amount of time is lost in its backward swing. Hence those methods of walking in which this occurs are not the most advantageous. Or if a person sinks into soft ground at every step, the necessary raising of the body leads to another loss of time. From similar reasons, persons who limp advance but slowly.

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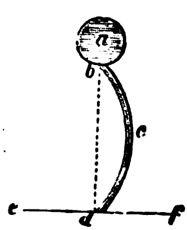
In such abnormal cases curved or slow movements of the progressive leg are sometimes associated.

1380. The act of running consists in an union of the movements of rapid walking with those of leaping. The body of the walker is always supported on one or both legs. The leaps which are connected with the act of running form intervals of time, during which the entire body is free in the air. It therefore oscillates greatly in the vertical direction. If the instants of leaping are diminished as much as possible, we get a rapid run, the steps of which are shorter than those of the leaping run. In this case the supporting leg loses as little time as possible in its action, and prepares beforehand for its swing.

1381. The leg, which is held fast in the hip-joint by the external pressure of the atmosphere (§ 96), may be regarded as a pendulum suspended thence, and having a swing the duration of which is determined by its length. It was found by W. and Ed. Weber, that the time required for a single step in the quickest possible walking almost exactly corresponded with that of half a pendulum vibration of the leg; amounting on an average to ·357, while the latter was ·353, seconds. A slower walk of course gives greater amounts of time. According to Weber, in the act of running they are also increased; and more by the leaping, than by the rapid, run.

1382. Let us suppose that the elastic rod planted upon the ground *e f* (Fig. 242), has been bent into the shape *b c d*, either by a weight *a*, or by any other force. On removing *a* there will be an elastic reaction (§ 51) of the particles of *b c d*, which will act through *d* upon the ground *e f* with the same amount of pressure *a* that was formerly exerted. But since the immovable ground reacts with a force equal to that which strikes it, the rod *b c d* springs up, as soon as these reactions overcome its gravity. Its gravity subsequently causes it to fall back, like any other propelled body on the loss of its active projectile force.

Fig. 242.



1383. The act of leaping depends on phenomena which are essentially the same. However various its several movements, they all coincide in the fact, that a greater or smaller portion of one or both legs is flexed, and then suddenly extended. Here the rapid and powerful straightening of curves exerts an influence similar to the elastic reaction of a curved rod (*b c d*, Fig. 242). And what has already been stated explains why a man easily springs from the solid ground, and even more forcibly from a stretched elastic rope. A previous run furnishes an ultimate velocity, which is capable of assisting to maintain the impulse of the leap that immediately follows. In all these cases, the arms may be used as regulating pendulums (§ 1326).

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1384. In creeping and climbing, the movements of progression are assisted by the upper extremities. Here the limbs are used in a way which somewhat reminds one of the four-footed animals. In creeping, we seek to advance along a more or less horizontal surface; and in climbing, up a perpendicular or steep one. In both, we first fix the arms, and then draw the rest of the body after them. When this has been done, the legs form the means of attachment, while the rest of the body is propelled forwards.

1385. The act of swimming depends upon the resistance which water furnishes when it is powerfully struck without being displaced to a corresponding extent. Here again progression is based upon circumstances similar to those of the act of leaping. The sudden extension which follows flexion, and the rotation of the arms in a curve backwards, act like oars, which, striking the water with their broad surface, make the boat itself move forwards in the opposite direction. And just as an oar ought to be feathered—*i.e.* brought back edgewise, so as not to cause an equal counter-movement—so the arms of the swimmer are brought forward again, bent against each other so as to occupy the smallest possible space. Since even after deep inspiration, the specific gravity of the human subject is generally greater than that of water (§ 41), small natatory movements are required as soon as the greater part of the body is under water.

1386. Most of our fresh-water fishes use the tail as a kind of steering oar. Here the stroke upon one side urges the animal forwards and towards the opposite one. Rapid successive strokes on each side alternately may produce a more rectilineal movement forwards. But they often give rise to small lateral deviations or a zigzag path. The other fins rarely afford more than a subordinate help to the movements produced by the tail. The gases contained in the air-bladder improve the mechanical momenta of the whole fish, as well as the mutual relations of its anterior and posterior parts.

1387. The act of flight is essentially a swimming in the elastic fluid medium of the atmosphere. The body of the bird is pervaded by many sacs, which are filled with gases and which, proceeding from the lungs, even penetrate the interior of many of the bones. Since these parts therefore contain warm air, the specific gravity of the whole animal is much less than what it would be if they were replaced by liquids or solids. But even were the air-sacs absent from the bones, their cavities would be filled with vapour where they contain no fat. Hence the large cavitary bones of the bird's skeleton greatly lighten its body, while the air-sacs which occur in many of them do not do so. The act of flight itself is accomplished, not by them, but by vigorous strokes of the broad expanded wings, and by the resistance of the atmosphere. Indeed, many animals which possess the power of flight possess neither air-sacs nor

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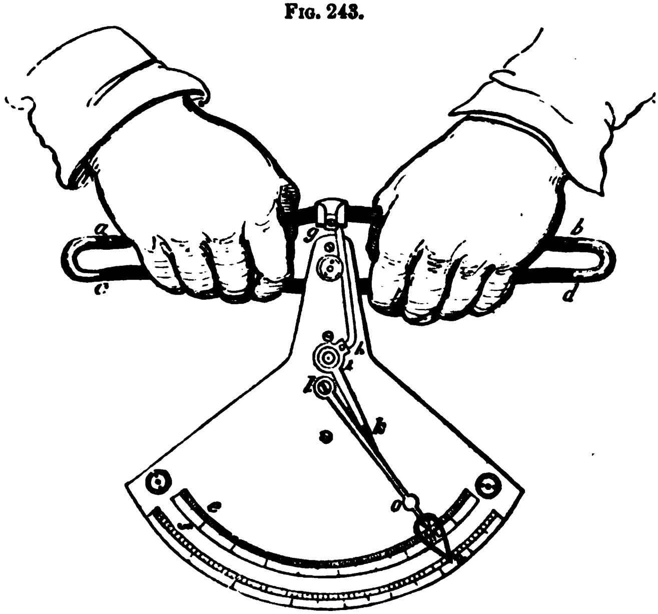
any structure which can be compared to them. And even the larger sacs may be opened without destroying the ability to fly. And however obscure the function of these organs, still it may be conjectured that their use is more closely related to respiration than to flight. Prechtl supposes that the air which they contain recedes towards the lungs, and thus assists in ensuring the continuance of respiration under many unfavourable circumstances,—such as prolonged singing, diving under water, or flight in the rarefied air of the higher regions. This observer further conjectures that, when greatly distended with air, they may serve as fulcra for the action of the neighbouring muscles.

1388. *Actions of Man as a machine.*—The action of the muscles furnishes a certain force of pressure or traction, which is capable of acting on foreign substances, or on the tissues of the body itself. For technical purposes, attempts have frequently been made to determine certain averages of the strength of man and animals, and to discover, by the aid of a mathematical analysis, rules which may be applied to practice.

1389. Regnier's dynamometer,—which is often used to determine the maximum pressure of the human hands, or the force of draught possessed by beasts of burden—consists of the spring balance represented in Fig. 243. The anterior plate which covers it has been purposely omitted

FIG. 243.



from the woodcut in order to allow an easier inspection of the whole. When the two hands press together the elastic spring plates, *a c* and *b d*,

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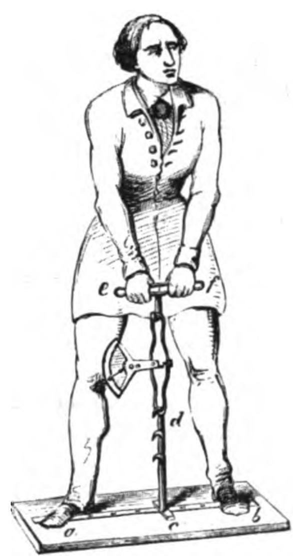
the angular lever *g h i k* pushes the index *l m* through a corresponding arc, which is given on the scale *e*. And if this is also graduated with units of weight for each degree, we may at once read off the number sought.

1390. The little reliance that can be placed on most spring balances, and the dependence of the result upon the skilfulness of the grasp, the suitableness of the muscular movements, and the rapidity of the impulse, make the results of these experiments but very approximative and variable. Besides this, it is evident that they only exhibit the maximum of an instantaneous effort.

1391. According to Quetelet, an adult man can exert a pressure of about 66 to 99lbs. with his right hand, from 57 to 90lbs. with his left hand, and from 123 to 196 with both. Under similar circumstances, women can exert a pressure of 48 to 55, 42 to 48, and 99 to 110lbs. respectively.

1392. In order to determine the tractile force of man, which is greatly affected by extension of the trunk, we make use of the arrangement represented in Fig. 244. The man treads upon a fixed iron plate *a b c*, from which proceeds a staff provided with hooks. One of these receives the curved part of the dynamometer *a c*, (Fig. 243). The second curved segment *b d*, (Fig. 243) hangs from the draught-hook *e f*, (Fig. 244). Hence the action here takes place in the direction *a b*, (Fig. 243). The index *l n* gives the corresponding amount of force on the second scale, *f*. In order to find the tractile force of a horse, the dynamometer is similarly interposed between the traces and the waggon.

FIG. 244.



1393. According to Quetelet, an adult man averages 205 to 342lbs. in this way, and the female 130 to 170. Forbes obtained much higher numbers for strong men of various provinces of Great Britain; Englishmen from 20 to 25 years of age gave 366 to 384lbs., Scotchmen 373 to 404, and Irishmen 397 to 413lbs.

1394. From experiments made at Bern it resulted that powerful men addicted to gymnastics raised with both hands a weight of 364lbs. about 2 feet in height.

1395. Even a person walking unladen exerts himself to a certain extent, since he sustains the weight of his own body for a certain distance at some definite average velocity. Let us suppose that he

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weighs 132lbs.; and makes 125 steps, of 31·5 inches, in the minute. His velocity per second will thus amount to $125 \times 31{\cdot}5 \div 60 = 65{\cdot}6$ inches. This makes about 236160 inches, or $3\frac{3}{4}$ miles, in the hour. If he can continue this movement about eight hours per day, it will give a daily result of $132 \times 3{\cdot}75 \times 8 = 3960$lbs. for one mile. Under such circumstances, the French engineers estimate the ordinary result at 4826·25 of these dynamic units.

1396. When a person has to carry a burden, it, and the fatigue which it causes, consume a part of the velocity and effective action. For instance, according to Morin, a man who carries a weight of $88\frac{1}{4}$lbs. on his back, presents a velocity of 29·53 inches per second. If he works seven hours daily, we get a result of $88{\cdot}25 \times 29{\cdot}53 \times 60 \times 60 \times 7 = 5953248 \div 12 \div 3 \div 1760 = 1036{\cdot}5$lbs. for a mile. But since the weight of the body is 132lbs., the effective action will be $(132 + 88{\cdot}25) \times 29{\cdot}53 \times 3600 \times 7 \div 63360$* $= 2586$ of these dynamic units, if the burden be borne during the whole period of movement. Hence we only obtain an effect equal to about half that of the unburdened labourer. And, other circumstances being equal, it will be less in ascending a mountain or a flight of steps, than on level ground.

1397. The maximum of exertion may effect extraordinary results for short periods of time. For instance, while the ordinary military step exhibits a velocity of somewhat less than 39 inches per second, swift runners can accomplish from 5 to 9 times this speed, so as to equal or exceed the cavalry trot or gallop. The latter maximum velocity was offered by West, but was not sustained for an entire minute. In like manner, a strong man can raise a burden of 330 to 440lbs. for a very short space of time. But the exhaustion which renders a frequent repetition of this impossible prevents great effective results from being thus distributed over wider periods of time.

1398. It has been frequently attempted to estimate, in dynamic units, the average results of the different kinds of work. These are divisible into two chief classes—one, in which the results consist in a horizontal movement; and another, where it is a perpendicular lifting. For instance, a labourer who carries 143·4lbs. on his back for a certain distance, and returns empty-handed, represents an horizontal effective action of 960·5lbs. for one mile, during a working-day of six hours: while a man who lifts 39·7lbs. by means of a pulley, and allows the cord to fall back again, represents a perpendicular effect of 106·45lbs. for a mile during the same period. But the great differences in the statements of different engineers sufficiently indicate that the estimates which we here start from are themselves subject to many variations, and are in many cases deduced from incorrect presumptions.

* The number of inches in a mile.

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1399. The same statement applies to the formulæ by which it has been attempted to determine the force of labourers in particular cases. The rule laid down by Gerstner is that most frequently made use of. Here the quotient of the actual and average velocity is subtracted from 2; as is also the quotient of the times occupied by the work. The product of these two magnitudes is multiplied by the medium force in order to obtain the power for the particular case.* This method presupposes that the weights and the velocity of average effects rise and fall in inverse proportion to each other. But the accuracy of such a theory may be doubted on physiological grounds (§ 1364).

* Thus supposing a burden of 30 lbs., carried 15 miles in 8 hours, to be a fair day's work, a man only walking 10 miles in that time could sustain ($= 30 \times (2 - \frac{10}{15}) \times (2 - \frac{8}{8}) =$) 40 lbs. On the other hand, if he has to increase his speed so as to accomplish the 15 miles in 6 hours, the burden ought to be reduced from 30 to ($30 \times (2 - \frac{20}{15}) \times (2 - \frac{6}{8}) =$) 20 lbs.—EDITOR.

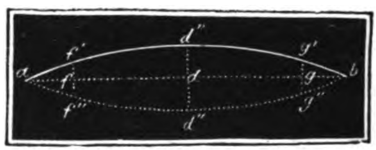
CHAPTER XVI.

VOICE.

1400. Those vibrations (§ 157) of ponderable matter which exceed a certain minimum of strength, and propagate themselves to the ear, evoke corresponding sensations of sound. A single powerful concussion gives rise to a sound; an irregular repetition of impulses to a noise; and their rhythmical recurrence, to a musical sound.

1401. Two kinds of sonorous undulations are met with: curved and molecular waves. Let us imagine *a b*, Fig. 245, to be a string fastened

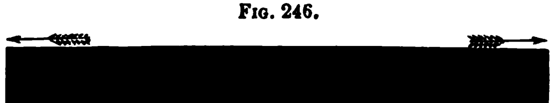
Fig. 245.



at both ends, and occupying, when in a state of equipoise, the position *a f d g b*. If we take hold of it at *d*, pull it towards *d′*, and then resign it to the operation of its own elasticity, it swings back towards *a d b*. The velocity thus attained then drives it towards the opposite side as far as *d″*. It then returns again, and repeats these curved undulations, but with constantly diminished extents or widths of vibration, *d′ d″*, owing to the constant loss of active force by the communication of impulses to neighbouring bodies. When this is altogether lost, the string rests in its position of equipoise, *a f d g b*. But the formation of sound ceases as soon as the movements lose the requisite strength and velocity.

1402. The compressive elasticity of the air (§ 67) frequently leads to molecular undulations, in which particular portions of the atmosphere are alternately rarefied and condensed. For example, on blowing into a tube which is open at both ends the gas present in the middle is

Fig. 246.



at a particular moment condensed, while that at both ends is rarefied, as illustrated by Fig. 246. Subsequently the reverse obtains, as shown by

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Fig. 247: *i. e.* the greatest rarefaction is at the middle, and the condensation at the ends.

FIG. 247.

1403. The height of the note depends upon the number of vibrations which occur in an unit of time; for instance, in a second. If we regard as unity the number of vibrations which correspond to the lowest note, the whole octave will be as follows:—

c	*d*	*e*	*f*	*g*	*a*	*b*	*c*
ut	re	mi	fa	sol	la	si	ut
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

Hence the next highest octave has twice, the third, *e*, $1\frac{1}{4}$, and the fifth *g*, $1\frac{1}{2}$ times, as many vibrations as the lowest note. The intensity of the musical sound is determined by the width of the vibration (§ 1401). Its peculiar character or "timbre" is connected with the molecular constitution of the vibrating substances, and is as yet unexplained.

1404. The formation of sound in stringed instruments depends upon the vibrations of stretched elastic cords; and in the different tubular instruments, upon the concussions of the columns of air which they contain. In both, the height of the sound is essentially determined by the amount of tension, and the length of the active substances. The tongue of an instrument is a lamina which is partially fixed, but has a free segment that can be made to vibrate by an external impulse. The metal plate *l l*, Fig. 248, which covers the greater part of the opening *a b c d*, repeatedly approaches and recedes from this aperture, when a

FIG. 248.

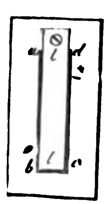

FIG. 249.

current of air is forced through it. If we fix two pieces of India rubber, or two elastic animal membranes, over the orifice of a tube, so that there remains a small fissure between them (Fig. 249), blowing into the tube causes these tongues to give out musical sounds. The application of a second tube over them produces a column of air which can greatly

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modify the results. The pipes of an organ are the best illustration of such musical instruments.

1405. The vocal organ of man and the higher animals may be best compared with a tongued instrument. The larynx, which is represented from the front in Fig. 250, and from the side in Fig. 251, is chiefly formed by the cricoid *a*, and the thyroid cartilage *b* (Figs. 250, 1, 2). They represent the box in which the tongues are fixed. If the larynx be

Fig. 250

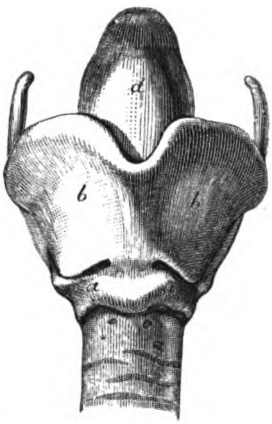

Fig. 251.

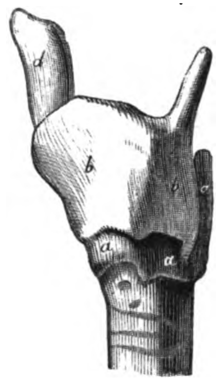

Fig. 252.

regarded from above, as seen in Fig. 252, and if the epiglottis (which is represented by *d* in all three figures) be turned outwards, we see behind it the two arytenoid cartilages, *c c*, which are placed over the cricoid cartilage, *a*. We may further observe the two chief tongues, the inferior or proper vocal cords, *e e*, which extend from the thyroid cartilage, *b*, to the arytenoid cartilages, and leave between them a fissure, the *rima vocalis*, or glottis. This leads on one side into the trachea, which lies below the larynx, and on the other into the cavity of the larynx itself, which communicates with the pharynx (*g*, Fig. 68, p. 125), and through it with the cavities of the mouth (between *c* and *d*, Fig. 68) and nose (*a*, Fig. 68). Above the proper vocal cords, *e e*, are extended two folds, the superior or ventricular cords *ff*, (Fig. 252), which are further from each other than the preceding. The depressions internal to these in the woodcut are called the ventricles of the larynx, a name which explains that of the cords themselves, *ff*.

1406. Just as the musician tunes his instrument by increasing or diminishing the tension of its vibrating strings, so something like this obtains with the tongues of the human larynx. Nature has placed here a series of small muscles, the contraction of which is capable of extending or relaxing the vocal cords. Many of them at the same time alter the width of the vocal fissure. We shall soon see that it is this arrangement

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which allows of singing and speaking, and enables us voluntarily to raise or depress the sounds of the voice. The human being is thus enabled to tune his instrument at will.

1407. These small muscles of the larynx are represented of their natural size in Figs. 253 and 254. The crico-thyroidei (*b*, Fig. 253, *a*, Fig. 254) and the crico-arytenoidei postici (*b*, Fig. 254) extend the vocal cords in the direction of their length, and at the same time narrow the glottis. The crico-arytenoidei laterales (*c*, Fig. 254) and the thyro-arytenoidei (*d*, Fig. 254) rather relax the vocal cords. The oblique and

FIG. 253.

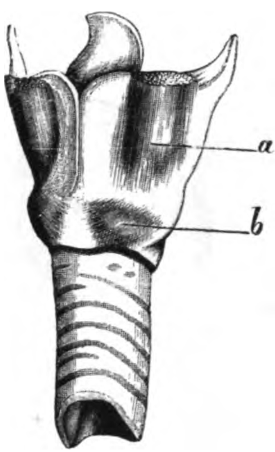
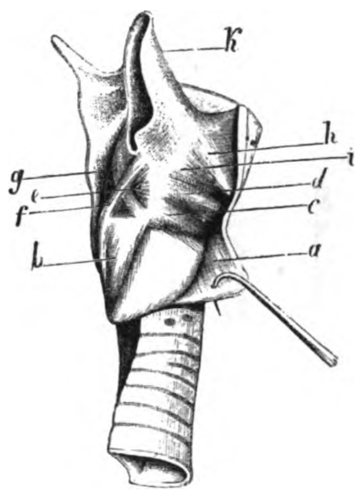


FIG. 254.



transverse fibres of the arytenoideus (*e* and *f g*, Fig. 254) close the posterior half of the glottis. This part of the glottis is called the respiratory portion, because it remains open during ordinary breathing, but is closed during the exercise of the voice by the mutual approximation of the vocal cords. Hence in the latter case there remains but a narrow anterior fissure, which bears the name of the vocal glottis. The epiglottis (*k*, Fig. 254) forms a valve which can be brought over the glottis by fine muscular bundles attached at *h* and *i* (§ 374).

1408. The action of the organ of voice, and the reason why it is fixed into the upper segment of the trachea, may be best explained by comparing it with the pipe of an organ. Let us suppose *t'*, Fig. 255, to be the wind-tube into which the air is driven from below, *b* the stopper in which is placed the tongue *a*, and *t* the body-tube. We will now place such a pipe *o* (Fig. 256) in the wind-box, *c c*, and drive in air from the bellows, *f f p*, through *t*. The air throws the tongue *a* (Fig. 255) into a state of vibration, and passes out in undulating movements from the

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body-tube. It is obvious that something similar occurs in the organ of voice. The lungs, the air of which is carried upwards in the bronchi, form the bellows; the larynx is the wind-box, in which are placed the tongues of the vocal cords; and the tissues of the pharynx, mouth, and nose, are body-tubes of various shape, the influence of which is diffused over the tongue-apparatus. And as these parts were independently requisite for nutrition, respiration, and some of the senses, Nature had only to interpose the vocal box of the larynx in some fitting situation between the bellows and the body-pieces, to form a musical instrument without the addition of any new textures.

FIG. 255.

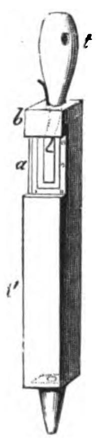

FIG. 256.

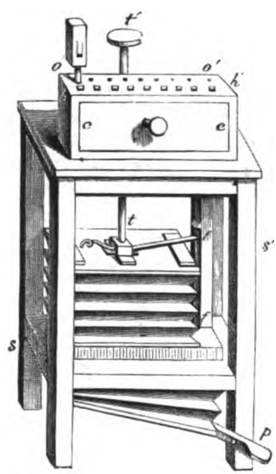

FIG. 257.

1409. Many of the vocal operations may be verified in the dead larynx. For this purpose we may either fix the prepared head of a corpse as represented (after Mueller) in Fig. 257, or may cut out the larynx alone. A thread, *e*, which passes over a roller to a scale, is so applied to the larynx that the tension of the vocal cords can be increased by placing a greater weight in the scale. We thus imitate the action of the muscles (§ 1406). The compressing apparatus seen in the wood-cut brings the vocal cords nearer to each other, and thus produces the requisite diminution in the width of the vocal fissure. The tube at *f* serves to convey the wind which throws the tongue-apparatus into action. By making use of the heads of the corresponding animals, we can imitate the voice of man, the barking of the dog, the grunting of the pig, &c.

1410. When the glottis is too widely open, we get a more or less in-

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distinct noise, and not a pure sound. The latter requires a certain narrowness of the glottis. This explains why the respiratory part is closed, and the vocal one narrowed, during singing and speaking aloud (§ 1407.)

1411. Other circumstances being equal, the height of the notes is raised by increasing the weight which extends the vocal cords in the apparatus represented at Fig. 257. And conversely, the artificial relaxation of these structures gives rise to lower notes. In this way a register of about three octaves may be produced. And even after all the parts which lie over the vocal cords (*e e*, Fig. 252) have been removed, these variations of sound may still occur.

1412. The strength of the wind injected at *f* (Fig. 257) produces two effects. It makes the sound more powerful; and thus regulates the transition from *piano* through *crescendo* to *forte*. And it can also partially compensate an extension of the vocal cords. For instance, J. Mueller found that when these were not stretched by any weight, and the pressure of the injected air amounted to 1·97 inch of water, *fis* was produced; while when the tension was six times as great, *dis* was sounded.* And conversely, within certain limits a more forcible extension of the vocal cords requires a smaller strength of wind to produce a note of the same height. These are called the compensative phenomena of the vocal organs.

1413. In the living animal, the lungs which drive up the air into the tongue-work of the vocal cords, may, in some cases, similarly assist to determine the height of the sound. But it is the vocal cords which essentially determine the production of higher or lower notes. Their clang or *timbre* is very different. This property of the sounds produced is greatly influenced by the vibrations of the elastic walls of the trachea and the bronchi, as well as by those of the remaining structures of the thorax and organs of respiration.

1414. The ordinary vocal sounds are produced at the instant of expiration. Hence the stream of air first causes the tongue-work to vibrate from below upwards (from *k* towards *i*, Fig. 128, p. 232). It always arrives here with an increased pressure. Cagniard Latour fixed a manometer (§ 86) into a tracheal fistula of the human subject, and found that vocal sounds of medium strength gave a tension of ·394 inch of quicksilver (compare § 760). More powerful sounds would obviously lead to greater amounts (§ 761).

1415. Expiration is not essential to the production of voice. During laughing, crying, yawning, and especially during sobbing (§ 755), inspiration is accompanied by loud sounds. This fact may at any time be verified artificially.

1416. Experiments on the dead larynx lead to the conclusion that the

* Corresponding to a rise from F sharp to D sharp, or nine semitones.—*Editor.*

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total register of the human voice can be produced by the inferior vocal cords alone. If we remove the whole of the larynx with the exception of the superior or ventricular cords and their neighbouring tissues, and if these be then mutually approximated, so as to leave but a small fissure between them, they may give rise to sounds like any other tongues would do. But since in the living subject they are further from each other, and lie above the inferior vocal cords, we are justified in doubting whether they ever produce independent sounds, or whether they can in any case exclusively determine the height of a note. Lately Segond[41]) has sought to prove that, in some mammals, the falsetto depends upon the superior, and the chest voice on the inferior, cords. Cats whose inferior vocal cords had been cut through at first entirely lost their voice, but eight days after were again able to mew: while injury of the ventricular cords permanently suppressed this vocal act. Dogs gave high or low cries of pain, according as their inferior or superior vocal cords had been rendered inefficient. The destruction of both led to a permanent loss of voice. But since the cats whose inferior vocal cords had been rendered useless did not immediately produce falsetto sounds, we are justified in entertaining strong suspicions of this theory, which attributes a divided action to these two kinds of vocal cords.

1417. At present we are unable to state how the ventricular cords act upon the clang of the voice; or whether the ventricles themselves, which render the vocal cords freer, and facilitate their vibrations, play an important part in this respect. Mayer and Noeggerath state that during the highest sounds, the human epiglottis lies horizontally, with its lateral margins rolled up. Magendie and Biot believe that it permits us to swell the sound without raising it. In this case it would act like the elastic covering of Grenié, which is sometimes placed over the tongue of an organ-pipe.

1418. The cavities of the mouth and the nose form, as it were, a double or bifid tube, which assists to determine the peculiar characters of the clang. This proposition is confirmed by a direct comparison of the sounds produced by the apparatus represented in Fig. 257, with those given out by the larynx alone. The difference between the ordinary and the nasal voice result from the manifold use which may be made of these two body-pieces.

1419. The vocal box formed by the larynx, frequently descends during low notes, and ascends during high ones. But in rare exceptions the reverse of this may obtain. Finally, in many cases it has no perceptible movement of any kind. Segond agrees with Dutrochet in supposing that the inferior constrictor of the pharynx (*i*, Fig. 71, p. 127) increases the tension of the vocal chords, when the larynx rises during the production of the higher notes.

1420. The bass, barytone, tenor, alto, and soprano voices, are distin-

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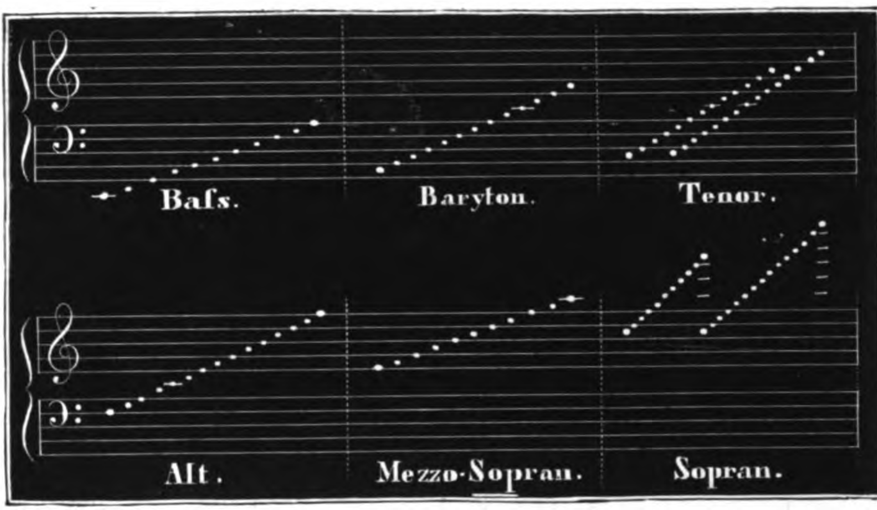
guished from each other, not merely by the height, but by the clang, of their notes. Their corresponding heights may be best represented by bringing together the limits usually ascribed to the kinds of voice thus named. We then obtain as follows :—

FIG. 258.



$$\underbrace{E \quad a}_{\text{Bass.}} \qquad \underbrace{A \quad f}_{\text{Barytone.}} \qquad \underbrace{c \quad \overline{a}}_{\text{Tenor.}} \qquad \underbrace{f \quad \overline{\overline{f}}}_{\text{Alto.}} \qquad \underbrace{\overline{c} \quad \overline{\overline{\overline{c}}}}_{\text{Soprano.}}$$

The absent semitones form stages of transition, which are allotted to one note or another, according to their clang and intensity. It is obvious that many of the notes which limit the different ranges may be given in several kinds of voice. The lowest *E* mentioned above corresponds to 165 vibrations in the second, and the highest $\overline{\overline{\overline{c}}}$ to 2112 (§ 1403).

1421. A good singing voice includes about 2½ octaves. But distinguished female singers are able to bring out an octave more.

1422. Women and children generally move in higher notes, in discant, soprano, or alto; and adult males in lower ones, in tenor, barytone, or bass. The period of puberty, during which the boy ripens into a man, and the girl into a woman, exerts an important influence upon the voice. About this time the voice, which previously moved in higher notes, breaks. During the rapid development of the larynx, the voice loses its purity. Its notes subsequently become more resonant, deep, and powerful. If the normal process of development is destroyed, morbid conditions of the voice are subsequently met with. Hence men whose sexual development is checked retain a delicate voice. The high notes

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of eunuchs depend upon this fact. And, conversely, women with an apparently masculine build of body have sometimes a deep and powerful barytone voice. In old age, the parts lose too much of their elasticity, and hence the resonant singing voice is lost.

1423. It has hitherto been found impossible to lay down any theory capable of explaining the different methods of singing with the chest-, falsetto-, and head-voice; or with the clear and veiled voice. But it is highly probable that the differences of the chest-voice and falsetto are greatly assisted by original diameter, and voluntary tension. We may conjecture that, in the higher notes of the head-voice, the vibrations are limited to the inner margins of the vocal cords.

1424. The strong current of air which occurs in the act of screaming will alone tend to raise its notes (§ 1412). Whistling and whispering depend upon the difficult passage of masses of air driven violently through narrow fissures.

1425. The glottis, and the more or less movable pieces of the double body-tube formed by the cavity of the mouth and nose, together produce the various sounds of speech (§ 1427). But all these structures are present in the higher animals as well as in man. And if, in spite of this, these creatures are devoid of speech, the fact does not depend upon mere minor peculiarities of the movable parts of their vocal organs. The chief cause rather lies in the lesser development of their nervous system. It is not merely the thoughts of the human mind which are betrayed by the conventional sounds of speech. We might rather say that the mind, and the arrangements of the nervous substance which are linked with it, constitute the only material way of sufficiently expressing the sensations. The imperfect speech of cretins and other imbeciles, or of patients who have undergone apoplectic seizures, is intimately connected with these circumstances.

1426. Hitherto the attempt to determine how the various articulate sounds are produced [42]) has only been made experimentally. Extraordinary patience has succeeded in constructing speaking machines, which deserve all possible acknowledgment from physiologists. The automaton recently prepared by Faber, and exhibited in most of the countries of Europe and in North America, may be regarded as the most perfect of all. Apart from the unnatural and unpleasant clang of its voice, the figure speaks quickly and plainly in various languages, when the corresponding keys are played upon. Its singing voice includes 12 notes (from *Re* to *La*), which sound very well when accompanied by a small organ.

Here the difference in the height of the notes is produced by varying the width of the glottis, and not by altering the tension of the vocal cords. This was done in accordance with the opinion—formerly universal, and now exploded—that the height of the sounds during life is determined by the condition of the glottis only.

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1427. The vowels are the only sounds the origin of which can at present be followed on acoustic principles. Every quick repetition of impulses gives rise to the perception of a vowel. When one string which hums in low notes produces *u*, and another which sounds in higher notes *i*, the difference of the impression depends upon the simple vibrations and the height of the note. But when an air-tube is placed before a tongue-work the conditions are more complicated. According to Willis, it is the length of the tube and the size of its orifice which determine whether *i*, *e*, *a*, *o*, or *u* is heard. Here the height of the note depends upon the number of vibrations of the tongue, while the nature of the vowel is determined by the height of the note which the tube would give as an open pipe (§ 1402). Hence an alteration of the tongue only affects the altitude of the note, and does not change the vowel.

1428. Many questions in comparative philology may be explained by a physiological examination of the pronunciation of the several sounds made use of in the different languages and dialects. This means of philological inquiry has been made less use of than it deserves. Every dialect is based on a particular adjustment, a special education, of the organs of speech. This explains why certain series of sounds have a peculiar effect; why a particular foreign language is more easily and perfectly spoken by the inhabitants of one country than of another; or why some of its accents sound like those of their mother tongue. Such physiological considerations frequently illustrate the destinies undergone by the same radical word in the course of time or in different allied languages; and even explain, in a surprising degree, many relations of quantity and metre.

1429. Many investigators have supposed that the chief means adopted by ventriloquists consists in the use of inspiratory sounds (§ 1415). This agrees with the well-known fact, that the notes are at that period higher, and that, if only of moderate intensity, they appear farther off. Many ventriloquists also make use of other means of deception. They cover the face with a cloth, in order that no play of features may attract attention to the person of the speaker. They often choose the form of an alternating dialogue, in which the use of different notes facilitates the error. And in speaking with expiratory notes, they sometimes distribute the air expelled at one expiration over a large space of time, and a considerable number of sounds.

1430. In the act of stuttering[43]) the several organs of speech do not play in their normal succession, but undergo contraction in a more aimless and uncertain manner. They are thus continually interfered with by convulsive impulses and inefficient adjustments. Many of the sounds altogether fail for some time, while others are frequently repeated before the whole word is completed, generally with a sudden explosion. The cause of this defect lies almost exclusively in the nervous apparatus

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which rules over the organs of speech. This explains why mental embarrassment, fright, the imitation of others, or affectation, may all lead to stuttering; and why a powerful will may conquer it. It is at the same time obvious that the cure can only be accomplished by proper educational means; and that all mechanical apparatus for the coercion of the tongue is useless:—as is also the section of the genio-hyoglossus (*a*, Fig. 67, p. 124).

1431. In deaf and dumb persons the organs of speech have originally no essential defects. The differences met with in these parts depend solely upon want of use. The true cause of their dumbness lies in their inability to perceive sound. The impossibility of appreciating the several sounds, and thus of gradually acquiring the proper adjustment of the organs of speech by comparing the sounds they produce, constitute the chief reason why the second infirmity is associated with the first. We sometimes find that adults who become completely deaf gradually forget their speech in the course of years, until they finally reduce it to a few words, or even lose it altogether.

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CHAPTER XVII.

FUNCTIONS OF THE SENSES.

1432. Every organ of sense consists of two portions. The first receives the stimuli, in order to their suitable preparation. The second, which pertains to the nervous system, gives them a peculiar elaboration, and at the same time brings about an action and reaction between them and the cerebral structures. In this way the eye consists of a series of refractile bodies which effect a suitable change in the images; the ear, of a chain of solid and fluid parts which conduct the waves of sound; the nose, of a ciliated mucous surface which takes up odorous particles; the tongue, of a covering which receives sapid substances; and the skin, of tissues which exert a definite influence upon the stimuli of temperature and pressure. While, on the other hand, the retina connected with the optic nerve of the eye, and the nerves of hearing, smelling, taste, and touch, lead to those vital reactions which succeed the impressions prepared by the above structures.

1433. An external object which is thus perceived produces an objective sensuous impression; since the first corresponding cause of excitement lies without the subject to be perceived itself. A number of men or animals may, with slight differences, simultaneously perceive the same luminous body. But when, on the other hand, the optic nerve or the part of the brain connected with it is compressed, burnt, or electrified, a person observes flashes of light which are visible to no one else. Hence we have here a purely subjective sensation. In like manner the auditory nerve is capable of responding to irritation with perceptions of sound; and the nerves of smell, taste, and touch, with similar corresponding impressions. In short, the distinction of sensations into objective and subjective is repeated in all the organs of sense.

1434. The several lenses of the healthy human eye contain no substances capable of casting shadows in the way of ordinary vision. But in certain artificial or morbid states the retina is capable of perceiving various substances present in the eye, like any external object. This is therefore essentially an objective perception of a body present within the organism. Still such a situation often causes the appearance just mentioned to be regarded as a subjective sensuous impression.

1435. Every organ of sense is specially adapted to a definite cycle of influences, or, as it is usually expressed, to its suitable or corresponding

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stimuli. To other impressions it responds either not at all, or at any rate not with its proper delicacy. Thus the eye only responds to the impulses of the waves of light, and not to the more forcible vibrations of ponderable matter. And changes of the latter, which are at most evident to the feeling of touch as a kind of trembling, give rise to the simple and specific sensations of sound in the auditory organs. While since the act of smell necessarily presupposes the gaseous or vaporous condition, the contact of any odorous liquid which completely fills the nasal cavities is only perceived by the nerves of touch, and not by the proper olfactory nerves of the mucous membrane of the nose.

1436. The five senses are incapable of appreciating all the changes of the external world. The movement of the waves of light, the impulses of ponderable substances, the hitherto unexplained action of odorous and sapid substances, and the alteration of pressure and temperature, form the chief stimuli which are distinctly recognized by the several organs of our senses. On the other hand, we have no special sensation of the influences of electricity and of magnetism. And active mechanical or chemical interference only gives rise to pain; *i. e.* to special changes in those nerves of sensation which, under different collateral circumstances, afford tactile impressions.

1437. We shall hereafter see that the nerve-fibres are much better adapted to perceive a change, than a permanency, of their state. Thus in point of fact, the eye only recognizes vibrations of the luminous æther, the ear those of ponderable matter: while the sense of touch only notices changes in the static relations, or in the balance of heat. It may be conjectured that the sense of smell also depends merely upon certain impulses; and that of taste, upon chemical operations which vary from one moment to another. Finally, pain depends upon the sudden or gradual production of certain deeper changes of the nervous structures. These require to be roused from their quiescent state, and must be maintained in a state of internal movement, as long as the corresponding action is to continue.

1438. *Sight.* The eye forms a globular mass, which is attached to the optic nerve as to a handle (Fig. 259), and is imbedded with it in the fat contained in the cavity of the orbit. From the orbit the optic nerve passes backwards, through a special aperture, into the cavity of the skull. Here the two nerves unite to form an azygos middle-piece, from which two nervous trunks again proceed to the brain. These circumstances are illustrated by Fig. 259.

1439. Since the rays which come from a luminous body follow certain prescribed paths, every telescope ought to be capable of rotation towards all parts of the sky, so as to suit every position of an object. Something similar to this occurs in the eye. In addition to the globe of the eye (*c* Fig. 260), fat (*d*), the optic and other nerves, and numerous vascular

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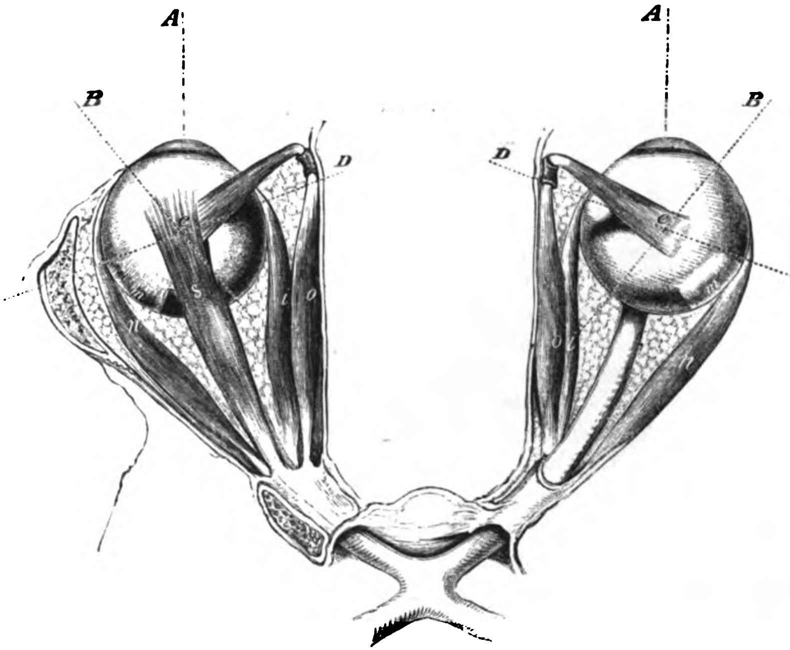
trunks, the orbit contains seven muscles. Of these all but one—the levator palpebræ superioris (Fig. 260, *g*)—are directly subservient to the movement of the globe, and assist to rotate it in all directions. They may be divided into four straight, and two oblique, muscles.

FIG. 259.



1440. When the internal rectus muscle (*i*, Fig. 259) contracts alone, the eye is turned inwards. In like manner the superior (*s*, Fig. 259) draws it upwards, the external (*n*) outwards, and the inferior, downwards.

1441. The superior oblique muscle (*o*, Fig, 259, *c*, Fig. 237, p. 399) runs along the upper and inner part of the orbit. It is then attached to a tendon, which passes through a special pulley (*e*, Fig. 237), is next bent outwards and backwards, and finally expands upon the outer and hinder part of the globe (*c*, Fig. 259, *f*, Fig. 237). We may imagine these circumstances represented by a vertical transverse section (Fig. 261); in which *a* corresponds to this tendinous structure. The muscle will therefore tend to rotate the globe in the direction of the arrow, *e e*; that is, it will carry the segment *c d* upwards and inwards. The inferior oblique muscle (*b*, Fig. 261) arises from the lower and inner part of the orbit, and arches outwards, to be finally attached to the eye externally and posteriorly (*m*, Fig. 259). It will therefore rotate the segment *c d* outwards and downwards in the direction of the arrow, *f f*.

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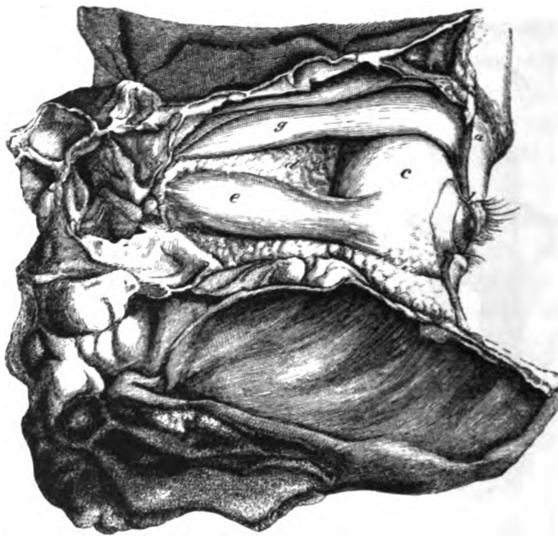
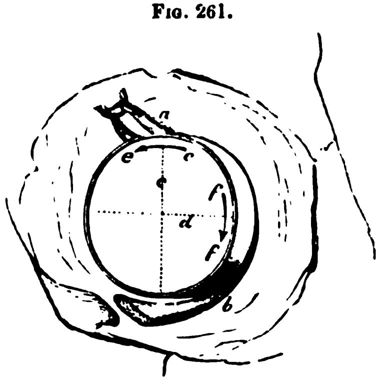
Thus the two oblique muscles have the direct effect of rotating the globe of the eye. But they are also capable of antagonizing undue

FIG. 260.



actions of the recti. For if two of these straight muscles contract simultaneously, they will not only roll the globe of the eye, but will also retract it towards the bottom of the orbit. The latter effect would be neutralized by a corresponding shortening of one of the two oblique muscles. The globe of the eye is thus enabled to move in the mean direction prescribed by the recti, without any absolute change in the position of its centre. These facts teach us that an apparently simple movement of the eye may demand the determinate and co-ordinate action of three muscles, or of half the contractile structures placed at its disposal (§ 1448).

FIG. 261.



1442. In a perfect sphere the axis of rotation occupies its centre. Supposing that the globe of the eye possesses this form, and that its axis, the length of which is generally from ·91 to ·98 inch, is in its diameter, the centre of rotation must lie from ·45 to ·49 inch behind the middle of the cornea. But such conditions do not really exist. It has therefore been attempted to ascertain the centre of the eye by experiment and calcu-

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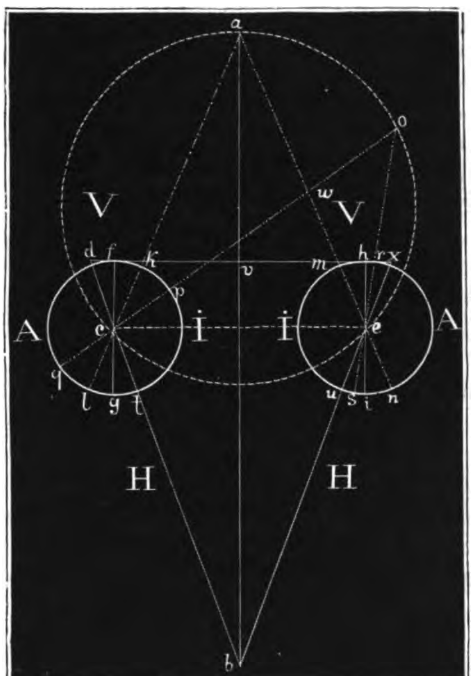
lation. In this way Volkmann obtained an average of ·484, Burow ·48, and the author ·488 inch for the horizontal, and ·45 for the vertical rotation. But the experiment which led to these results includes numerous sources of possible error. Hence we can only say that the centre of rotation lies nearly in the middle of the axis of the eye.

1443. The accompanying diagram (Fig. 262) may serve to explain the

FIG. 262.



most important circumstances relating to the simultaneous movements of both eyes. At *c* and *e* are indicated the centres of rotation of the spheres which, for the sake of simplicity, represent the organs of sight. V V is anterior, A A is exterior, H H posterior, and I I interior. Since those points are most distinctly perceived, the images of which are mirrored in the middle of the yellow spot of the retina (Tab. I., Fig. 14), we always direct the globe of the eye so that its prolonged visual axis,—*i.e.* the straight line which passes through the middle of the spot or axis, and the middle of the cornea,—falls upon the luminous point which we wish to see most plainly. When we fix both eyes on it at once, the two axes of vision must intersect each other in it.

1444. Let us suppose that the two axes of vision (*f g* and *h i*, Fig. 262) are originally parallel, and that we endeavour to get a more exact

perception of the point *a*,—which lies in the middle line, *a b*, and in the same plane as the centres of rotation, *c* and *e*. The axis *f g* is then turned inwards towards *k l*, and *h i* towards *m n*, so that *l k a* and *n m a* meet in *a*. Hence both globes are rotated inwards towards the middle line, *a b*, so as to acquire the necessary angle of convergence, *c a e*.

1445. But if, on the other hand, we suppose that the point *a* lies external to the middle line, *a b*—for instance, at *o*, which is nearer the right eye—the right axis of vision, *h i*, must move outwards *r s*, and the left inwards towards *p q*, to attain the angle, *c o e*. Here the two eyes have to a certain extent opposite actions. The one rolls inwards, and the other outwards, in order that both may be fixed on *o*.

1446. If the point *a* lies higher or lower than the horizontal plane the surface of which is represented by Fig. 262, the visual axes of both eyes must be elevated or depressed to a corresponding degree. It is obvious that this case does not permit the double contingency which we have just explained.

1447. Putting all this together, we find that looking upwards or downwards always presupposes an uniform action of the corresponding upper or lower muscles of the eye. While the two kinds of rotation which correspond to the position of points lying in the horizontal plane are very different, both as regards their direction, and the muscles on which they immediately depend. The act of looking inwards (towards *a*, Fig. 262) requires two movements, which are designated by the same word, the impulse to both being furnished by the two internal recti muscles. But if we compare them with the original and parallel direction of the axes of vision, *f g* and *h i*, we shall find that the movement is in reality unharmonious, and constitutes a squint, since *m n* and *k l* deviate towards the same side, towards the line *a b*. And, on the other hand, when we look outwards (towards *o*, Fig. 262), the external rectus of the nearest eye, and the internal rectus of the more remote one, act together. The former rolls outwards, and the latter inwards, so that we get opposed movements. But notwithstanding this, the movements are harmonious; since the variations from parallelism (from *f g* and *h i*) are directed towards the same side.

1448. The statement that a single rectus muscle suffices for the adjustment of the eye, is rarely correct. A more exact study of the mechanism of these muscles indicates that a second rectus generally assists, while an oblique muscle secures the immobility of the centre of rotation (§ 1441). But in looking inwards, this complicated play is effected by similar agents; while in looking outwards, it is done by what are in part antagonists.

1449. It is evident that when the axes of vision, *k l* and *m n*, are adjusted to the point *a*, their deviation from parallelism, *f g* and *h i*, will be less, the greater the distance at which *a* lies from the centres of rotation, *c* and *e*. When the distance is indefinitely increased, the external

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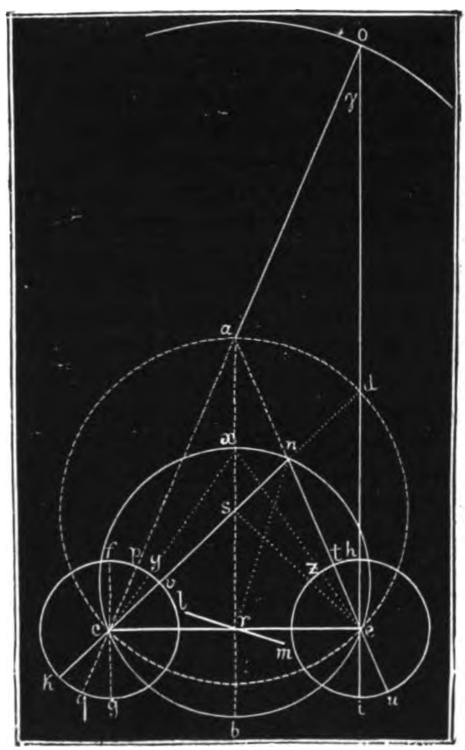
angle of their direction $c\,a\,e$ becomes so small, that it may be regarded as $=0$. And as in this case $a\,c$ and $a\,e$ may be considered parallel, so in looking at very remote objects, the eyes are also said to be parallel. But it is obvious that this expression is in its strictest sense incorrect, since the produced axes of vision will always intersect each other in a certain point.

1450. We have already (§ 1447) seen that the act of looking at a luminous point lying in the line $a\,b$ (Fig. 262) requires an inharmonious movement of the eye, which we characterized as a squint. The abnormal and permanent squint consists in the fact that the axes of vision are not parallel even when in a state of rest. Under such circumstances one or both organs of vision deviate more or less considerably in all positions.

1451. Thus while during the act of looking into infinite space the normal axes of vision would be in $f\,g$ and $h\,i$ (Fig. 263), that of the left

FIG. 263.



and squinting eye would be in $p\,q$. So that in the state of rest the two axes, $q\,o$ and $i\,o$, intersect each other at o. When the person desires to perceive the point a with both eyes simultaneously, the left and abnormal eye need not be moved at all, while the healthy right eye must describe

an arc, $h\,t$, which corresponds to the angle of the squint, $f\,c\,p$. The near object x necessitates the small angle of rotation $p\,c\,y$ for the squinting eye, and the larger one $h\,e\,z$ for the healthy one. In general terms, the angle of squinting affects all the movements of the eye as some constant positive or negative value.

1452. The inward squint,—in which the axis of vision $p\,q$ deviates from its normal position $f\,g$,—may depend on insufficient length or excessive contraction of the internal rectus muscle. It may also be due to paralysis of the external rectus muscle, when the internal acts more freely, from having lost the resistance naturally presented by its antagonist. Thus for instance, we often find that the left eye of a patient suffering from hemiplegia of the same side of the body begins to squint inwards. But we are not justified in asserting that this phenomenon will always follow inactivity of the external rectus. For this muscle may be divided in the living animal without the instant (or even the subsequent) occurrence of an inward squint.

1453. The abnormal circumstances which have just been explained in the case of the internal rectus sometimes obtain with others of the recti muscles : so that a person may squint outwards, upwards, or downwards, as well as inwards. Deviations upwards or downwards are, however, very rare. And although the outward squint is often met with, still on the whole, it is less frequent than the inward one. The former is generally associated with serious lesions of the retina, which are followed by blindness.

1454. Immoderate contraction of one or both oblique muscles will obviously cause certain irregularities in the movements of the eye. It has been supposed that the eye then remains abnormally rotated around its antero-posterior long axis : giving rise to what is called a rotary squint. But the accuracy of this supposition must be established by further researches.

1455. The abnormal muscular shortening which causes squinting may be permanent. Here it occurs under all circumstances, and may be recognized either at once, or after a careful analysis of the phenomena. But in some instances this morbid contraction only appears under certain collateral conditions. We have seen (§ 1430) that persons otherwise fluent speakers may begin to stutter in consequence of mental impressions. In like manner, there are many persons who only squint when embarrassed.

1456. Finally, there is a peculiar kind of squint which depends upon the fact that one eye either cannot be moved at all, or at least not beyond a certain limit. This has been distinguished from the moveable kinds previously described by the name of the fixed or immoveable squint.

1457. A ray of light (§ 157) passing in the same medium always

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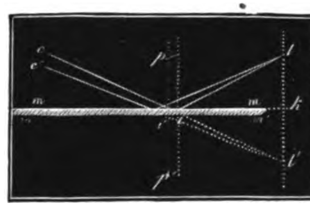
takes a rectilineal course. But when it meets with a medium of a different kind, four different effects may result. Part of the light is dispersed on all sides, while another part is reflected in a regular or prescribed path. If the new medium be transparent, part will pass onwards in a refracted state. Finally, part is absorbed or lost in the interior, probably by partial reflection and interference (§ 165).

1458. Let us suppose *m m* (Fig. 264) to be a plane reflecting surface, and *l i* an incident ray of light; the line *p p'*, perpendicular to the point of contact *i*, makes with it the angle *l i p*, which is called the angle of incidence. The reflected ray *c i* furnishes the angle of reflection *c i p*, the amount of which coincides with that of the angle of incidence *l i p*.

FIG. 264.



1459. The angle *m F m'* (Fig. 265) at which the rays of light proceeding from *F* towards *m m'* strike against a concave mirror, becomes less, the further *F* recedes from *m m'*. And when the distance is greatly increased, it diminishes so much, that there is scarcely any error in regarding the rays as taking a parallel course,

FIG. 265.

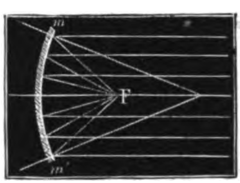
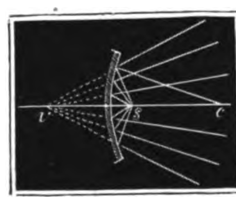


FIG. 266.



instead of proceeding from a single point. Striking in this way upon the mirror *m m'*, they undergo reflection, and are united in the focus, *F*. And conversely, rays which come from this focus are reflected parallel to each other. The place where the rays from a terminable distance converge to meet each other, or their mutual focal distance, varies with the distance of the luminous point, and the form of the mirror. It is real when it lies before the mirror, as at *F* (Fig. 265); and virtual when it lies behind it, as at *v* (Fig. 266).

1460. It depends upon the distance of objects, whether their several points have real or virtual foci in concave mirrors, and whether the whole is represented of natural, increased, or diminished size. Convex mirrors, such as the cornea and the anterior surface of the crystalline lens, always possess virtual foci.

1461. The angle of incidence of a ray of light *e f*, which passes through a transparent medium *a b c d*, (Fig. 267) will be *e f o*; supposing *o i* to be

perpendicular to *a b*. If its path remained unaltered, it would pass onwards in *f g l*. But when the new medium has a greater refractile power than that out of which the ray *e f* comes, the latter is bent towards the perpendicular *o i*, so that its path *f h* forms a smaller angle *h f i* than its rectilineal prolongation *f g l*. A less refractile medium produces the reverse effect. When the ray re-enters the atmosphere, its angle of incidence *g h f* is less than its angle of refraction *n h k*.

1462. When the two media traversed by the ray remain unaltered, the quotients of the sines of the various angles of incidence and the corresponding angles of refraction form a constant magnitude, which is designated the index of refraction. This law was first deduced by Snell

FIG. 267.

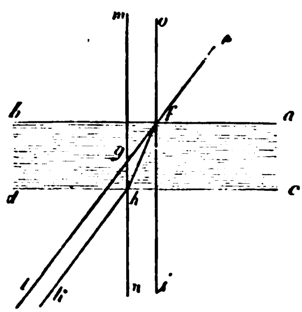
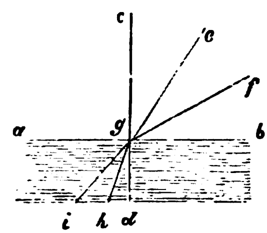


FIG. 268.



and Descartes, and is hence often called by their names. Thus, in Fig. 268, the sine $c\,g\,f \div$ sine $i\,g\,d =$ sine $c\,g\,e \div$ sine $h\,g\,d = n$, which is constant. But all these angles will be between 0° and 90°. Hence the sines increase with the angles themselves. Now, since in the more refractile medium the angle of refraction is smaller than the angle of incidence (§ 1461), it follows that the index of refraction, reduced to a less refractile medium, must be greater than 1·. While in the converse case it will be less than 1·.

1463. It is usual to compare substances with air or empty space in order to express their index of refraction in simple numbers. For example, when that of the cornea is said to be 1·33, this means that a ray of light passing from the air into the cornea is so refracted, that the sine of the angle of incidence divided by that of refraction amounts to 1·33.

1464. The index of refraction of the aqueous humour of the eye is 1·338. But when a ray of light passes into it from the cornea, the relative index of refraction is found by dividing 1·338 by 1·33. Hence 1·006 is the magnitude sought for.

1465. When *a b* and *c d* (Fig. 267) are parallel to each other, *h k* and *e f* also remain parallel, so that the ray is not bent from its original

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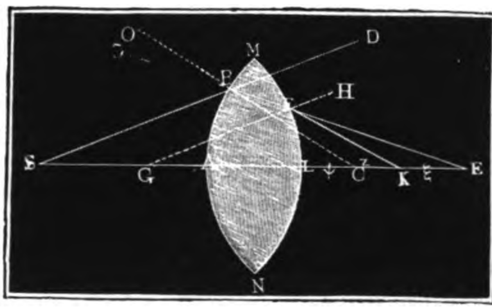
direction, but is only a little displaced. But when the surfaces of transit are not parallel, a deflection really occurs. The refractive phenomena of prisms, and of the various kinds of lens, depend upon these circumstances.

1466. The surfaces of a convex lens are segments of the surface of a sphere. The radius of these segments is called the diameter of their curves. Now if we suppose M A N L (Fig. 269) to be a symmetrical double convex lens, C B the diameter of the curve formed by the anterior

FIG. 269.



M B A N, and G F that of the posterior surface M F L N, the line A L, which lies within G C, will be the axis of the lens, and its middle the optical centre. A ray which passes in the line S G C E is called an axial ray. When the luminous point S lies in the course of S E, the ray which is produced in a straight line from this to meet the axis A C passes unbroken as an axial one. But where the lens consists of a more refractile medium than the air out of which the light comes, every other ray is refracted as shown in Fig. 269.

For example, the ray S B has the angle of incidence O B S; since it may easily be shown that the prolongation O B of the diameter of the curve B C is the perpendicular of incidence. Now supposing the smaller angle C B F (§1461) to be the angle of refraction, the ray will continue along B F within the lens. It will then pass, at F, from a more refractile medium into one which is less so. Its angle of incidence is now B F G. But if H F K be its increased angle of refraction (§ 1461) it will pass in F K, and will intersect the prolonged axis S E, in the point K. And dismissing for the present the circumstances of spherical aberration, we shall find that all the other rays which proceed from S at any angle will also pass through K. The point of this union forms the mutual focus of S; *i.e.*, when the luminous point is at S, all the rays coming from it resume the form of such a point by uniting at K. And conversely, the luminous point K will have its focus at S. But here the point of union forms a real focus; since it lies behind the

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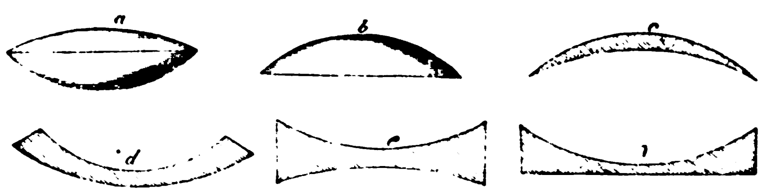
lens, and the luminous point is placed before it. If both lay on the same side, the focus would be virtual (§ 1459).

The ray B S leaves the prolonged axis S G at a certain angle B S A. Hence it is divergent with respect to B A. The first refraction B F diminishes the divergence; since the angle of refraction F B C is smaller than the angle of incidence O B S. The second refraction at F increases the convergence. For supposing F E produced from B F, the angles B F G and H F E will be equal to each other. But H F K must be greater than H F E. If the ray S B were not refracted at all, but proceeded in S B D, it would for ever deviate from the prolonged axis S E. The first refraction, which occurs at B, so changes its course as to make it intersect the prolonged axis in E. The second at F causes it to meet the prolonged axis still earlier in K. Hence the double refraction causes a speedier union in the common focus.

1467. There are six varieties of spherical lens. The bi-convex or double convex *a* (Fig. 270) has both surfaces curved outwards, as in the example detailed above. The plano-convex lens *b* has one projecting spherical surface, and a second which is plane. The meniscus has a convex and a concave surface: either the former *c*, or the latter *d*, being the more curved of the two, and having a smaller diameter. The double concave lens *e* possesses two excavated surfaces; and finally, the plano-concave lens *f* has an excavated and a plane surface.

Fig. 270.



1468. The lenses *a*, *b*, and *c* are called collective, because they collect the originally divergent rays in such a way that the latter reunite behind them. On the other hand, *d*, *e*, and *f* form dispersive lenses, since they tend to increase the divergence. Hence the foci of the former are real, since they lie on the opposite side to the luminous point; while those of the latter are virtual, or on the same side.

1469. Parallel rays (§ 1459) converge to unite in one point, which is called the chief focus of the lens. And conversely, the rays which proceed from this chief focus become parallel after their refraction. The images furnished by a lens are produced by the refraction of point for point, in conformity with the situation and distance of each.

1470. We have hitherto avoided all consideration of spherical aberration (§ 1466) or of that deviation which is due to the spherical shape. We must now learn what is meant by this term, and with what reason

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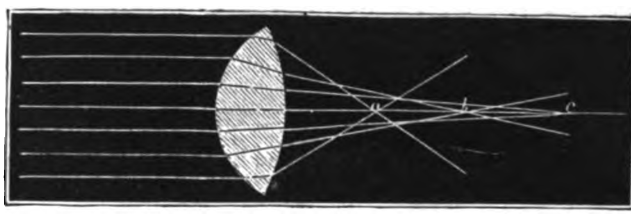
the peculiarities thus presented may in many instances be dismissed from notice.

Let us suppose that Fig. 271 is a double convex lens, and that the line *a b c* occupies its prolonged axis; the several parallel rays will have what are, strictly speaking, different chief foci. It may be proved that those rays which penetrate the lens further from its axis unite behind it sooner than those which reach the refracting substance nearer its centre. Thus the chief focus of the former is at *a*; while that of the latter

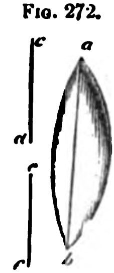
FIG. 271.



is placed at *b* or *c*. This statement applies to all finite rays; *i.e.* to all rays that come from a luminous point which is too near to allow of their being regarded as parallel. The distances *a b*, *b c*, correspond to the amount of spherical aberration. This will necessarily render the image of the point more obscure, since it will prevent all the rays from intersecting in the same transverse plane to form it.

1471. When the rays are not far from the prolonged axis, the spherical aberration is but small, and may without error be disregarded. And in a lens that has slight curves with large diameters, the difference of the angles of the external and middle divergent rays is also diminished. Hence lenses of this form are frequently selected, in order as much as possible to avoid spherical aberration. But when it becomes necessary to work with a lens (*a b*, Fig. 272) which offers, on the whole, a considerable spherical aberration, we seek to diminish it by the use of a septum or diaphragm. A partition with a perforated centre (*d e*, Fig. 272) is placed before the refracting body (*a b*), in order to cut off the outermost rays. The remaining central rays furnish no spherical aberration worthy of notice.

FIG. 272.



1472. Let *V W*, Fig. 273, represent a double convex lens, having its chief foci at *F*,—a distance which in both cases equals that of the corresponding focus *F* from the optic centre (§ 1466) of the lens *V W*. If we now place an object *A B* at from once to twice the focal distance, we shall get a real, inverted, and magnified image, *b a*. When it lies at more than twice the focal distance,—so that *a b* may be regarded as the

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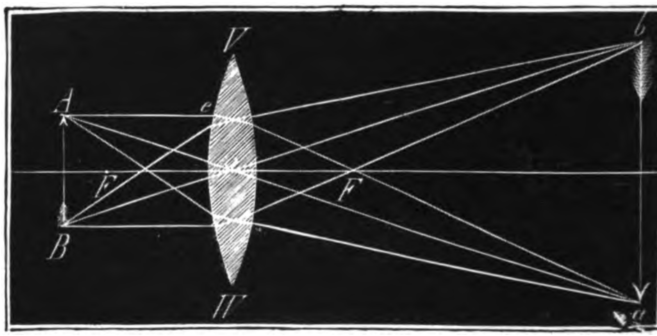
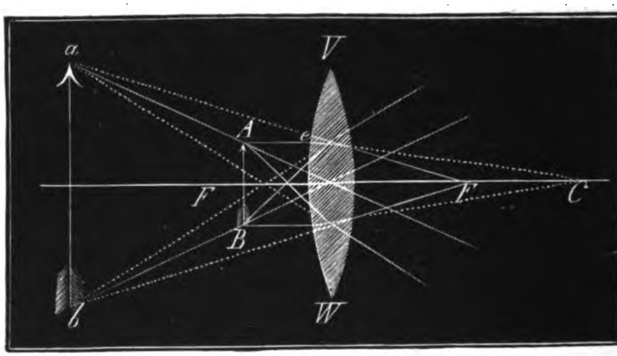
image from which the rays of light proceed,—we get a real, inverted, and diminished image, *A B*. Finally, when the luminous body, *A B*, Fig. 274,

FIG. 273.



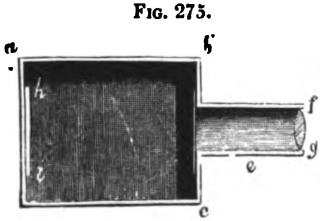
stands between the principal focus *F*, and the lens *V W*, we obtain a virtual, upright, magnified, and more distant image, *a b*.

FIG. 274.



1473. A *camera obscura* consists of a box, *a b c d*, Fig. 275, which is blackened internally, and has a posterior surface fit for the reception of images — such as is formed by the plate of ground glass, *h i*. Its tube *e* has anteriorly a double convex lens *f g*, which produces a suitable refraction of the rays. When an object is placed at more than twice the focal distance of *f g*, we see upon *h i* an inverted and diminished image, the size of which constantly decreases (§ 1472) with an increasing distance of the luminous point. But since the focal length varies with the distance of the object, the tube *e* must be capable of being lengthened or shortened, so as to allow of the situation of

FIG. 275.



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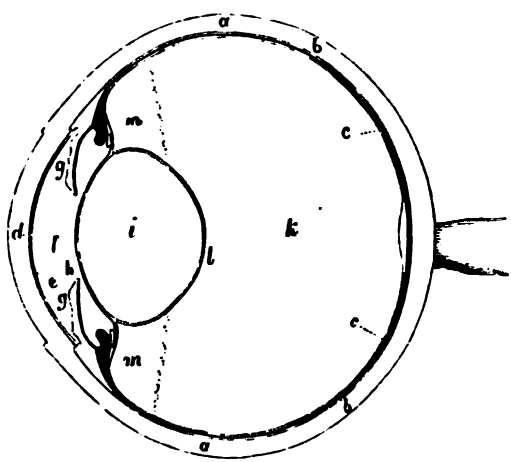
the lens being altered in a corresponding degree. We are thus enabled to adjust the focus of this optical apparatus to different distances. The greater the absolute distance of the luminous body itself, the smaller the differences of focal length become. This explains why, for all ordinary purposes, comparatively slight alterations of *e* will suffice.

1474. The eye is essentially such a camera obscura, which instead of enclosing a space filled with air, is entirely occupied by special refractile substances. The sensitive retina forms the ground on which the images must be mirrored in order to their being perceived.

Fig. 276 represents a section of the several parts of the eye. Here *a a* is the sclerotic or hard coat, to which the optic nerve is fixed posteriorly like a handle, and of which the anterior segment forms the white

FIG. 276.



of the eye. The black choroid, which is indicated by *b*, corresponds to the darkened sides of the camera obscura; while *c* is the retina, upon which the images are pourtrayed. The letter *d* corresponds to the transparent cornea; *e* to the thin membrane of Wrisberg, which is firmly united to the back of the cornea; *f* is the aqueous humour, which fills the anterior chamber—*i. e.*, the space limited by the membrane *e*, the iris *g*, and the pupillary aperture *h*,—and extends to the posterior chamber behind the iris. The iris, *g g*, is the part on which the colour of the eye depends. The aperture of the pupil, *h*, is sometimes called the black of the eye. The crystalline lens, *i*, is enclosed in a proper covering, the capsule of the lens; and occupies a special circular fossa, *l*, in the anterior surface of the vitreous body, *k*. The ciliary body, which is spread over the remainder of the anterior surface of the vitreous humour, lies in front of *m m*.

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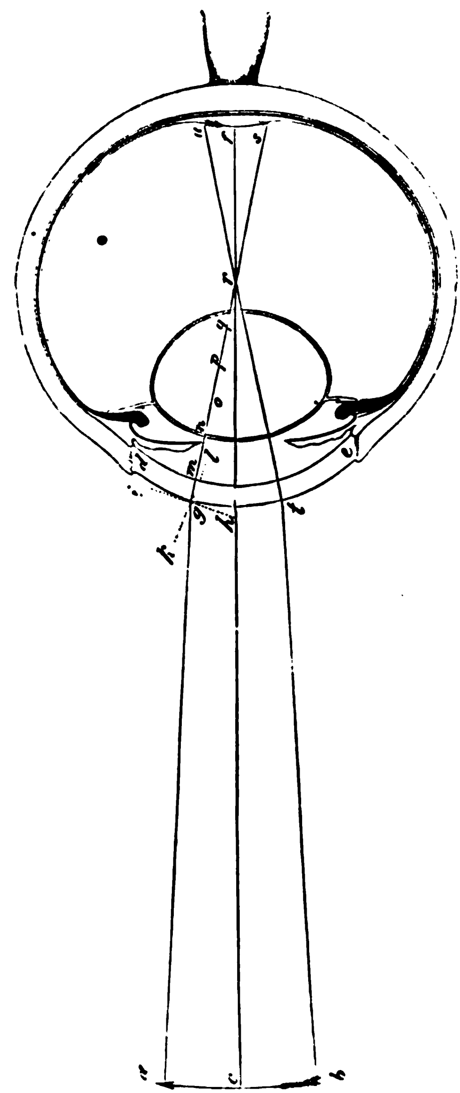
1475. Let us suppose that $a\ b$, Fig. 277, is an object giving out original or reflected rays of light, which impinge upon the cornea $d\ e$. Two actions will ensue. One part of them will be reflected, while another will pass onwards refracted. The reflection gives rise to a mirrored image; and the refraction to that image which is pourtrayed upon the retina, and is essential to perception.

Fig. 277.



1476. The lustre of the eye is due to those rays which are in part dispersed, in part regularly reflected (§ 1457), by the surface of the cornea (§ 890). Since the convex cornea itself consists of a number of transparent layers intimately united to each other, it gives one or more virtual mirrored images (§ 1459). The anterior surface of the lens is capable of acting in the same way: while the posterior surface behaves like a concave mirror. Hence if a candle be held near the eye, we may, with a favourable lighting, remark at least three diminished and reflected images. Those due to the convex mirrors formed by the cornea and the anterior surface of the lens are upright. But that which corresponds to the posterior surface of the lens is inverted, because the focus of this concave mirror falls inside the eye. This experiment, to which attention has been drawn by Purkinje and Sanson, has been proposed as a means of recognizing the commencement of cataract, or opacity of the crystalline lens. For it is obvious that when the pos-

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terior reflecting surface of the lens becomes opaque, the inverted image will vanish. And where both surfaces of the lens have lost their reflecting properties, the action of the cornea will alone remain. It has often been stated that we may thus recognize opacities which cannot be seen at first sight. But experience rather contradicts this assertion.

1477. The phenomena of refraction are evidently the main purpose of the eye. When the object *a b* lies at more than twice the focal distance of the cornea *d e*, we get an inverted and diminished image like that seen in a camera obscura when the luminous body has a corresponding remoteness. The course of the rays of light may be explained in detail by Fig. 277.

Supposing that *k l* is at right angles to the tangent *h i*, and hence corresponds to the perpendicular of incidence, the ray *a g* will have *k g a* for its angle of incidence, and *l g m* for its angle of refraction. Since the cornea has a greater index of refraction (1·33) than the air, the refracted ray *g m* will approach the line *g l*. And since the relative index of refraction for the aqueous humour amounts to 1·006, *m n* will be still more bent in the same direction. The crystalline lens exhibits, as a whole, a refractility which even exceeds that of the cornea and aqueous humour. But we are not justified in believing that it is therefore the most powerful refractor of the rays which enter the eye: for these enter it from the aqueous humour; so that the question is only decided by its proportional index of refraction. But this is smaller than that of the cornea, when the latter is compared with atmospheric air. Hence *n q* proceeds from a new bend,—which is, however, less marked than that between *g m* and *a g*. The refractility of the vitreous body approaches that of the watery humour. Hence the crystalline lens is surrounded on all sides by pretty equal refractile forces. There is therefore a new and slight deviation in *q s* (§ 1466). Since the ray *q s* reaches the retina in the point *s*, the uppermost point, *a*, is mirrored as the lowest in *s*. And in the same way the point *u* corresponds to the point *b*. Hence the retina at *u f s* presents an inverted and diminished image of *a c b*.

1478. But such a description only includes the more general relations of the path taken by the rays of light. Many of the details have been purposely disregarded,—indeed only part of these can be investigated in an optical manner. The non-spherical curves of the refractile bodies in the eye, their stratified structure, their varying refractility, and the probably imperfect centres of the lenses, unite to render all exact examination very difficult.

1479. Those refractile media which are not fluid—such as the cornea, the crystalline lens, and the vitreous body—correspond in the possession of a stratified structure. The influence which this peculiarity exercises on the optical phenomena may be best investigated in the crystalline lens. This contains a number of layers, enclosed within each other

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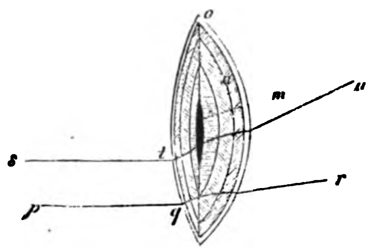
like those of an onion. The innermost of these, *m* (Fig. 278), form what is called the nucleus or kernel, and exhibit the greatest density and refractility. The middle layers, *n*, are less remarkable in both these respects; and the outer, *o*, are still less so. Finally the semi-fluid *liquor Morgagni*, which lies between the capsule and the proper substance of the lens, offers what is probably the smallest refraction. We have, in one word, a *polyzonal* lens, in which the refractive power increases continually from the surface towards the nucleus *m*.

FIG. 278.



1480. Owing to this arrangement, a ray *p q r* which only passes through the external layers, will be less refracted than a second *s t u*, which also passes through the nucleus. In addition to this, it may be shown mathematically that this arrangement increases the index of refraction to an extent which is almost incredible at first sight. For example, according to Senff, this amounts to 1·37 for the outermost layers, 1·45 for the nucleus, and 1·54 for the whole mass. Thus the latter has a higher general value than the nucleus itself, although this offers a greater number than any other constituent part.

1481. But the true object of the polyzonal structure of the lens can hardly be explained as a mere increase of the index of refraction; for Nature might easily have attained this purpose in a much simpler way. On the contrary, it is far more probable that the chief purpose of this peculiar arrangement is to secure certain collateral advantages which are revealed by optical considerations. And especially, the amount of spherical aberration (§ 1470) is thus diminished. The lens may therefore have more convex surfaces; or can allow the passage of more numerous rays, which will produce clearer and brighter images.

1482. Supposing *h i* (Fig. 279) to be the retina, a point *k* will be plainly seen when its image is mirrored upon the retina as a point *o*, or when the total effect of all the refractile bodies of the eye produces a mutual focus at such a distance as to touch the retina *h i*. But if, on the other hand, the latter lay at *p q*, we should have what is called an anterior dispersive circle *r s*, instead of the corresponding point *k*. For the refracted rays would not be collected into a point, on account of the focus *o* being behind the retina *p q*. If the latter were at *t u*, there would be a posterior dispersive circle *v w*. The rays already united at *o* would again separate from each other before reaching the nervous coat. And since these circumstances must always hold good, it is only when the last union of the various refractions in the eye falls upon the retina itself,—and neither before nor behind it,—that we

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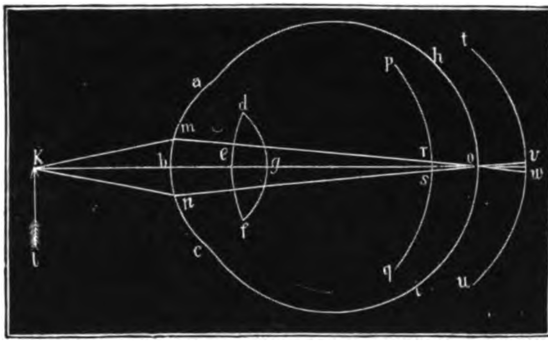
get an image which corresponds to the object, or a perfect and satisfactory perception.

Fig. 279.



1483. We shall hereafter find that these conclusions are more or less confirmed by long- and short-sighted vision. In addition to this, it has often been attempted to prove by calculation that the images of infinitely remote objects would necessarily strike the retina of the dead eye. But there are many circumstances which deprive these calculations of all certain basis. For the sake of simplicity, one must presuppose that most of the refractile bodies of the eye, the cornea, the aqueous humour, and the crystalline lens, have spherical surfaces (§ 1478). Their curves, their thicknesses, and their refractility, all vary in different eyes. And hitherto no one has been able to determine their numerical values in a single healthy human eye. Besides this, many parts are necessarily altogether disregarded :—such are the capsule of the lens, the liquor Morgagni, and the small quantities of fluid between the capsule of the lens and the vitreous body, and between this and the retina. Hence these calculations at best only exhibit something like the real state of the case. They are indeed useful in many further approximative calculations, such as will be referred to hereafter. But they do not furnish any mathematical proof, such as would vanquish all doubts, and establish definite numerical results.

1484. We will suppose *a m c* (fig. 280) to be the object seen, and *b o d* its inverted image upon the retina : *a b*, *m o*, and *c d*, or the straight lines which unite any two corresponding points of the luminous substance and the reflected image, are the lines of direction taken by the luminous points. The common point of intersection *x* is called the optical centre, and the angle *a x c*, which is opposite and equal to *d x b*, is called the visual angle of the object *a b*.

1485. When the distance *m n* is so great, that *x n* or even $o\,n = 0$ in comparison with *m n*, it matters very little where we place the optic centre *x*. Hence, for looking at the stars, or other very distant objects,

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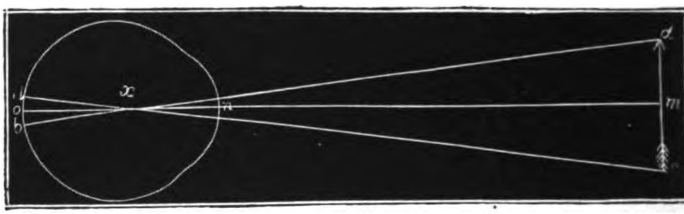
astronomers place it in the middle of the pupil—(somewhat behind *f*, Fig. 276.) But since in looking at nearer bodies the length of *x n* with respect to *m n* cannot be disregarded, it has often been attempted to fix the site of the optical centre more exactly. It would appear that it lies in the interior of the lens, and is capable of advancing and receding visibly, though slightly, according to the varying distances of luminous bodies.

FIG. 280.



1486. If, for the sake of simplicity, we regard *a m c* and *b o d* (Fig. 280) as straight lines, we shall have two triangles, *a x c* and *b x d*, in which the opposite angles at *x* are equal to each other. If we further suppose that *o m* bisects *b d* and *a c*, and is perpendicular to both these lines, then the triangles *a x c* and *b x d*, *a x m* and *d x o*, and finally *m x c* and *o x b*, will be similar, each to each. Hence knowing the magnitude of the luminous body *a m*, and its distance *x m*, we might calculate its visual angle *a x m*, and the size of the image on the retina *o b*. And where *n m* is so great that *x n* may be altogether disregarded, we need only reckon the distance of the object from the cornea, or *m n*.

1487. The visual angle of the sun amounts to somewhat more than half a degree, and the diameter of its image upon the retina to about $\frac{1}{254}$th of an inch. We shall hereafter see that this amount may be even lessened without disadvantage.

1488. The focal distance of any particular lens (§ 1466), or of any system of refractile bodies, depends essentially on the distance of the luminous object. But the smaller the distances of the luminous bodies, the more quickly do its differences increase. For example, in the eye, so long as the distances lie between the utmost remoteness and $16\frac{1}{2}$ inches, it only amounts to fractions of $\frac{1}{25}$th of an inch. While the difference between $16\frac{1}{2}$ and $4\frac{1}{3}$ is many times that fraction of an inch. Hence, in order to the distinct vision of objects both far and near, the adjustment (§ 1473) is chiefly required for those points which are not very distant.

1489. There is a maximum and minimum distance at which a luminous body can be plainly seen; and the interval between the two forms the limit of vision. But however definite both of these may seem to be, a closer examination shows that they really are not so. To say nothing

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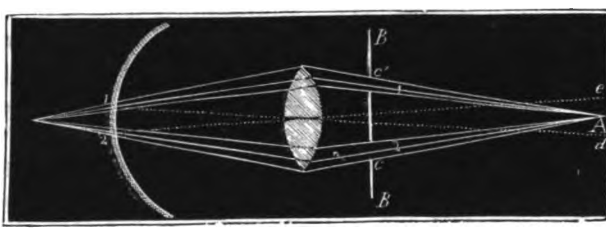
of the differences presented by the eyes of different persons,—bulk, form, lustre, and colour, essentially affect the distinctness of perception. Finally, it is impossible accurately to state the limits where complete distinctness ceases, and indistinctness begins.

1490. The optometers commonly made use of to find the average length of vision, are based upon a fact which is best illustrated by the experiments of Scheiner. For this purpose we make use of a screen, which has two small fissures or round apertures. The distance of these from each other must be less than the diameter of the pupil. On looking through these at a small object—for example, at a stretched thread, or a pin—the body is seen single so long as it is within the limit of vision, but appears as a double image when this is not the case. The cause of this phenomenon may be explained by Fig. 281. We will suppose *A* to be a

FIG. 281.



luminous point, *B B* the screen with the holes *c* and *c'*; the cone of light 1 goes through *c'*, and 2 through *c*. When *A* lies within the natural range of vision, its converse focus falls upon the retina depicted as an arch in the figure. Since in this case the rays return to a point, the two openings, and the dark wall between them, will injure the distinctness with which it is seen, without exerting any other influence. But if *A* is too near the eye, so that the converse focus falls behind the retina as shown in the figure, we shall have two separate dispersive circles, 1 and 2, since the part of the screen between *c* and *c'* allows a corresponding interval of the retina to remain unlighted. We shall hereafter see that we refer each image outwards to a situation which is the opposite of its true one. The more indistinct view produced by 1 is therefore referred to *d*; and that of 2 to *e*. Hence the double images perceived have opposite situations. When a semitransparent or coloured glass is brought before *c'*, this reacts upon *d*, and *vice versâ*. But if, on the other hand, *A* lay too far from the eye, so that the converse focus of *A* fell before the retina, every injury of *c'* would be transferred to *e* and not to *d*.

1491. The proposition upon which the optometer is based may therefore be explained by Fig. 282. Supposing *a b* a stretched thread, *c* will

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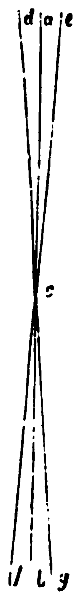
indicate the limits of the visual range, in which the image remains single. The double images, *d c* and *e c*, as well as *f c* and *g c*, indicate the ranges of excessive distance or proximity. If a black wire be stretched upon a semitransparent ground, and placed upright and moveable upon a measuring rod, it may be moved upon this, until it begins to appear double through two narrow fissures. In this way either of the two limits of visual range may be directly read off on the measuring rod.

Fig. 282.



1492. We have seen (§ 1473) that the neck of the camera obscura (*e*, Fig. 275, p. 440) must be shortened or lengthened, and that a telescope or microscope must be properly adjusted, in order to adapt the whole to correspond to the distance of the luminous point. But the eye sees at all distances. Hence it has been often attempted to find the cause of this capacity of adjustment. At present, however, the question has not been satisfactorily answered. Many of the suppositions hitherto made may easily be refuted; and none of the theories advanced rest on sufficient proofs.

1493. It has already been remarked (§ 1482), that dispersive circles, the diameter of which increases with the distance of the focus, appear within and beyond it. But the indistinctness of the images increases with their size. If we imagine the retina capable of distinctly perceiving the points which are mirrored in certain limited dispersive circles, a considerable amount of adjustment would thus be permitted. The theory of Sturm is based upon such suppositions. Since none of the refractile bodies of the eye possess a spherical form, it may be questioned whether a simple focus ever really obtains, and whether there is not always a streak of light, in which the place of greatest brightness varies with the distance of the luminous body. And if, supposing this to be the case, the capacity of distinct perception could be extended to greater limitary distances, all special capacity of adjustment would seem to be superfluous.

1494. The fact that a man, who has been looking at near objects for some time, recognizes remote ones less distinctly in the instant that follows, might be interpreted in two ways. It might depend upon the after-effect of the (so to speak) habituated nervous function. But it is also possible, that many of the internal changes required for near vision are effaced but slowly; and the more so, the longer they have previously continued.

1495. Many have supposed that the form of the lenses of the eye undergoes an essential change during near vision. Since in this case

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the focus falls behind the retina if the eye is originally adjusted to indefinite distances, the difficulty might be overcome by an elongation of its axis, or a greater curve of its cornea. Assuming that the eye formed a yielding sphere, the contraction of its muscles might possibly satisfy this requirement. But the living organ of sight is a tense mass, and objects both far and near are perceived in all positions of the eye; so that this opinion is, *à priori*, very improbable. Besides we may see by the telescope and microscope, that the form of the cornea is unchanged during far and near vision; and that, in the latter case, its centre does not project. And the adjustment (§ 1494) sometimes seems to demand a greater time than would be required for a mere change in the condition of the striped muscles of the eye.

1496. Many have thought that adjustment was aided by changes in the diameter of the pupil. In near vision with both eyes, the pupil certainly becomes narrower. But this chiefly depends on the fact, that the eyes must then converge inwards, in order that their axes should intersect in the near point (§ 1444). And it may be shown theoretically that the changes in the size of the pupil are too small to explain the capacity of adjustment. While, if only one eye remain open, objects both far and near may be plainly seen without any alteration in the diameter of the pupil.

1497. The relations of the crystalline lens afford what seems to be the most probable explanation. A very slight increase of its curves would cover all differences of focus. Its stratified structure would give it an advantage in this respect over a simple uniform mass, since its common index of refraction (§ 1480) increases as the diameter of its curve decreases. And if, in addition to this, the lens could be shifted forwards, an adjustment by means of such minute changes would be greatly facilitated. But it may be questioned whether Nature really or exclusively makes use of this assistance. Indeed, it is probable that the capacity of adjustment is not entirely destroyed by the loss of the crystalline lens.

1498. Recent microscopical researches have called attention to certain contractile structures in the interior of the eye. The chief of these is the tensor of the choroid coat, which Bruecke has described as lying in the structure formerly called the ciliary ligament. In man and mammalia, both it and the iris possess unstriped muscular fibres; while, in all birds hitherto examined, they are striped. It is possible that many other structures, such as the zonula of Zinn, possess a capacity of gradual contraction during life; and may perhaps aid in adjusting the eye. The after-effect mentioned at § 1494 might thus be more easily understood. But it is obvious that all these conjectures attempt to explain a fact, the very existence of which is still open to some doubt.

1499. The defect called short-sightedness or myopia is due to the point of furthest vision being too near. While in long-sightedness, or

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presbyopia, it is the nearest point that is too distant. Hence in the former case the range of vision is too far; and in the latter it is too near. But since the smaller the distance of the luminous point, the greater are the differences of focal distance, it follows that a long-sighted person possesses a greater range of distinct vision than a short-sighted one.

1500. All circumstances which permit too strong a refraction lead to short-sightedness, while the converse conditions produce long-sightedness. Let us suppose that the retina of the healthy eye lies at *k i*, Fig. 279, so that the common focus *o* of the luminous point *k* falls upon it, then if *k* be too distant, *o* will lie before the retina *t u* of the short-sighted eye. This therefore sees the inverted dispersive circle *v w*; and hence *k* becomes more indistinct, the more *v w* is diffused, or the farther it lies from *o* (§ 1482). While, conversely, if we imagine that *p q* is the retina of the long-sighted eye, and that *k* lies too near, so that the common focus is at *o*, we shall have a corresponding dispersive circle *r s*, which will again obscure the visual perception.

1501. These facts explain what kind of spectacles each of these defects requires. Concave refracting bodies, such as concave glasses, or dispersive lenses (§ 1468), increase the divergence of the rays which proceed from a point. If we interpose such an eye-glass between the too distant luminous point *k*, and the cornea *a c*, of the short-sighted eye, *k m* and *k n* will impinge on the latter as if the angle *m k n* had been widened. Hence *m o* and *n o* will converge less, and intersect later. When the dispersive lens is a suitable one, it shifts the point of intersection *o* exactly on to the retina *t u*.

And, conversely, convex glasses or collective lenses will enable a long-sighted person to perceive near objects distinctly. In this defect the unassisted retina *p q* sees the dispersive circle *r s*. The interposition of the collective lens makes *k m* and *k n* (and therefore *m r* and *r s*) converge more strongly. Hence *o* can be shifted so far forwards as to light upon the place occupied by *r s*. Since we are here concerned with the adjustment of great differences (§ 1488) in the focus of small distances, that addition to the visual range which any collective lens can effect will be smaller, but will imply more active changes, than the preceding.

1502. That excessive refraction which causes short-sightedness may be immediately dependent on too great a curvature of the cornea or crystalline lens, or on too high a refractive index, or too great a thickness of the crystalline lens,—all of which would cause too great a length of the axis of the eye. Hence persons whose eyes are large and prominent, or over-distended with fluid, are often short-sighted. While since the succulence of the different parts of the body diminishes in the later years of life, the sight of such persons frequently improves on the approach of old age. And, conversely, long-sightedness depends

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upon insufficient refraction, or too great a shortness of the axis of the eye. The reason just mentioned explains why persons who have previously seen objects both far and near with perfect distinctness, require in their old age a glass which collects the rays.

The short-sightedness so often met with in the higher classes is rather due to education than to any original defect of construction. A person who is frequently reading or writing, or a woman who is constantly engaged on fine needle-work, may gradually become short-sighted. The prolonged adjustment of the eye to near objects gradually leads to permanent conditions, which more or less withdraw the perception of distant luminous objects from the influence of the will. The improper use of spectacles then frequently increases the defect. A short-sighted person who uses too strong a concave glass for looking at distant objects, may be said to force his eyes to become continually more short-sighted. Hence we cannot be too careful in the selection of spectacles. And when a short-sighted person reads or writes without laying aside his concave glasses, it is obvious that he is treating the small and near letters as if they were at a great distance. He thus becomes continually more short-sighted, and gradually has to pass on to a stronger eye-glass.

1503. And, conversely, this influence of education on the eyes enables us to effect a gradual diminution in the degree of short-sightedness. If a person strive to read and write at constantly increasing distances, his eye will, in favourable cases, gradually yield. The reading-desk * invented by Berthold effects this by regulating the distances of the letters from the eye.

1504. It is generally assumed that the medium visual distance amounts to about 9·8 inches; being shorter in short-sighted, and longer in long-sighted, persons. In order that spectacles should improve either defect, they must alter the results to those which would obtain, supposing the objects at the natural visual distance. Hence the number which represents this is an element of the compensation which is produced by the action of spectacles.

The spectacles sold in shops are indicated by numbers, which allow of their power being estimated. Each of these numbers corresponds to a certain focus of a collecting or dispersive glass, and hence, to a certain degree of long- or short-sightedness. But the numbers used by different makers, or even by the same person, do not always correspond. The medium visual distance is also differently estimated. Hence these numbers alone cannot be trusted to.

1505. From what has been previously stated, it follows that where the crystalline lens—one of the chief refractile bodies—is completely wanting, the strongest collecting lenses will be required. The opera-

* This apparatus is sometimes called the Myopodiorthoticon.

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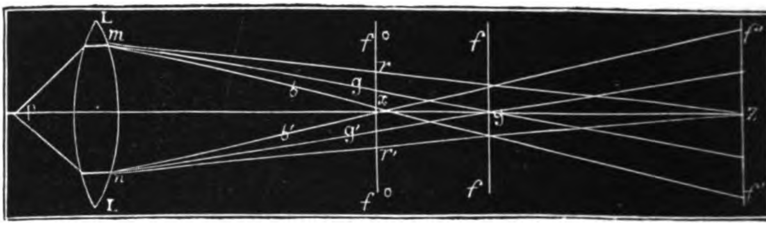
tion for cataract produces such a deficiency (§ 1065). Hence the spectacles used in these cases are the most powerful convex lenses ever called in to aid the abnormal sight.

1506. We have (§ 161) already seen that the chromatic appearances of optical instruments, and of the living eye, are due to the unequal refrangibility of the several coloured rays. The phenomenon of chromatic aberration may be illustrated by Fig. 283. Supposing that the

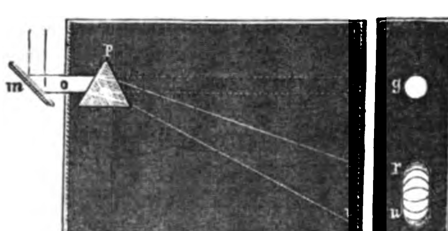
FIG. 283.



point p gives off colourless light, which is a confused mixture of all the coloured rays, these will be unequally refracted in the lens $L\ L$. The red, $m\,r$, which are least refracted, only unite at z; the violet, $m\,b$, which are most strongly refracted, at x; and the yellow, $m\,g$, at some intermediate place, g. The screen $f\,f$ has yellow in its middle, and intersections of red and violet at its circumference; $f^{\circ}f^{\circ}$, violet in the centre, and yellow and red at the periphery; and, finally, $f'f'$ is red in the centre, then yellow, and still more externally, blue. In fact, chromatic aberration is evinced by the image due to the originally colourless light being white in the centre, while it is edged around by the colours of the rainbow. The numerous concurrent colours cover each other at the centre, so that the eye cannot distinguish them separately; while at the periphery, their separation is greater.

1507. When the solar ray reflected from a mirror m (Fig. 284), is allowed to pass through an opening o into a dark chamber, a colourless circle of light g (Fig. 285) of corresponding magnitude is produced.

FIG. 284. FIG. 285.



The rays take a rectilineal course from o to impinge upon the screen, which receives them at g. But when a glass prism p is interposed,

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the rays are refracted towards $r\ u$. And the unequal refractility of the several coloured rays (§ 161) causes $r\ u$ not only to appear broader than o, but to exhibit the seven primary colours of the spectrum (§ 161).

1508. More exact observation shows that the coloured spectrum exhibits a great number of dark streaks, such as are represented (magnified) in Fig. 286. These lines form a convenient basis for determining many details relative to refraction. For the neighbouring colours of the spectrum merge into each other so gradually, that the selection of particular lines allows of much more definite statements. For example, the place B is selected as the limit of the red, and H of the violet light, since the shades of these colours which lie beyond them gradually elude recognition (§ 214).

1509. The amount of chromatic aberration or dispersion in any substance corresponds to the difference in the indices of refraction of B and H. For instance, a particular kind of flint glass gives 1·628 for B, and 1·671 for H; hence ·043 is the amount of its dispersion. On the other hand, a certain kind of crown glass gives 1·524 for B, and 1·545 for H; so that here the aberration only amounts to ·021. Hence the dispersion does not increase and decrease with the index of refraction. Upon this fact depends the construction of achromatic lenses.

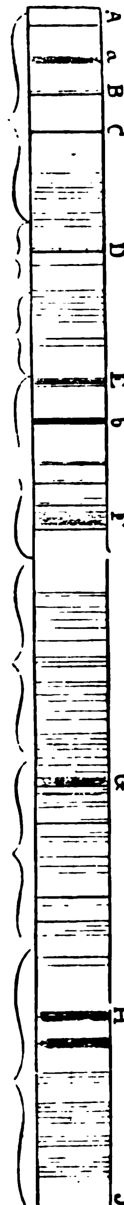
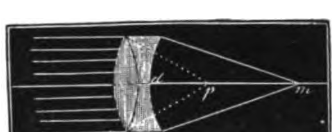


Fig. 286.

1510. A single lens is incapable of affording perfectly achromatic images. But this end is better attained by a suitable combination of two. Thus supposing a collective lens of crown glass, and a dispersive one of flint glass, united together as shown in Fig. 287, their mutual

Fig. 287.



relations of curvature, thickness, and distance, might be so arranged as to remove much of the chromatic dispersion. If the anterior collective lens alone were present, the parallel incident rays would unite in the chief focus p, and the whole amount of dispersion belonging to the crown-glass would come into action.

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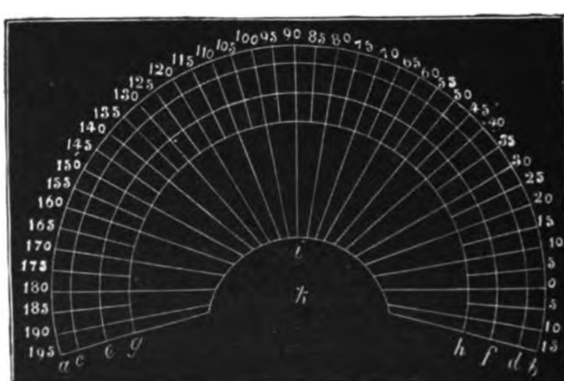
But since the concave lens of flint glass immediately follows, and is penetrated by the converging rays as shown in Fig. 287, these can only unite to a focus subsequently at *m*. Hence an achromatic combination of lenses causes a lengthening of the focal distance, and is so far detrimental, as that it diminishes the size of the images (§ 1472). But since flint-glass has a stronger dispersive power than crown-glass (§ 1509), we may arrange them in such a way as to remove by the concave lens a great part of the chromatic aberration due to the convex one, without losing the main result of the refraction—the magnified image. At the same time, a careful examination will show that none of the combinations of lenses called achromatic can do more than remove a great part of the aberration:—they never completely overcome it.

1511. But the same proposition holds good of our own eyes, which are anything but absolutely achromatic. On the contrary, delicate experiments show that the influence of the different indices of refraction of the several colours makes itself felt in the healthy eye. It is true that in ordinary vision no coloured fringes can be noticed. But the experiment of Scheiner (§ 1490) shows that derangements of this kind easily occur in the perception of those objects which lie beyond the limits of the visual range.

1512. We have already (§ 1486) found that the size of the visual angle determines the extent of the image on the retina. But experience teaches us that there are here two limits of distinct perception —a maximum and a minimum.

1513. The maximum value may be determined by the apparatus represented in Fig. 288. It consists of numerous graduated semicircles

FIG. 288.



having a common centre at *k*. The lower part is so cut out, that the centre of rotation of the eye (§ 1442)—or its optic centre (§ 1484)—can be made to coincide with *k*. If fine needles be now placed as sights, and

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shifted from one degree to another, the eye being fixed straight forward on 90°, it will be found that their images become more indistinct, the further they are carried outwards, until finally they altogether disappear. Those, for instance, which stand at an angle of 87° to 93° may be seen with perfect distinctness; while externally to this they are constantly more indistinct, until at last, beyond 50° and 130°, they cease to be seen at all. It results from hence that we do not perceive the whole extent of the images which touch any part of the retina. On the contrary, we have but a limited region of distinct vision, around which are placed layers of constantly decreasing distinctness, until finally all satisfactory perception becomes impossible.

1514. The axis of vision adjusted to 90° falls upon the middle of that yellow spot which is seen in the human subject when not examined too recently after death. The deviation of 3° on all sides, which about corresponds to the region of greatest distinctness, demands less than ·04 inch of distance on the retina. Hence the region of direct and distinct vision belongs to the yellow spot; while that of indirect and indistinct perception lies external to this, and projects into that part of the retina which remains of a greyish-white colour after death. But this yellow spot is absent from almost all animals, and only appears gradually in early childhood. Hence even were this colour present during life, it would not be essential to visual perception.

1515. At present we cannot explain why the function of the retina is limited in the way just described. As little can we determine theoretically the minimum of the visual angle, and of the images on the retina. But experience teaches us that here also there are certain limits, beyond which all distinct perception is impossible.

1516. Let us suppose $a\,b$ and $i\,k$ (Fig. 289) two objects of different size, and n the optic centre (§ 1484) of the eye. It is obvious that in spite of this difference, if $o\,n \div e\,n = a\,b \div i\,k$, we shall have the same visual angle, $a\,n\,b$, and retinal images of equal extent. If the nearer object $a\,b$ be opaque, it will cover the larger one $i\,k$, and a still larger one $c\,d$ will only be visible by its side portions, $c\,i$ and $d\,k$. In one word, the amount of the visual angle, and the size of the image on the retina, depend upon the mutual relations of size and distance in the luminous body. Hence when any object is invisible from its too small visual angle, this condition may be due either to the distance being too great, or the object too small, or to a combination of both these causes. The optical arrangements which counteract this defect are therefore divisible into two classes. The telescope improves our vision of objects which are distant, and therefore apparently too small; and the microscope of objects which, in spite of their proximity, are invisible from minuteness.

1517. The minimum visual angle depends not merely on the strength

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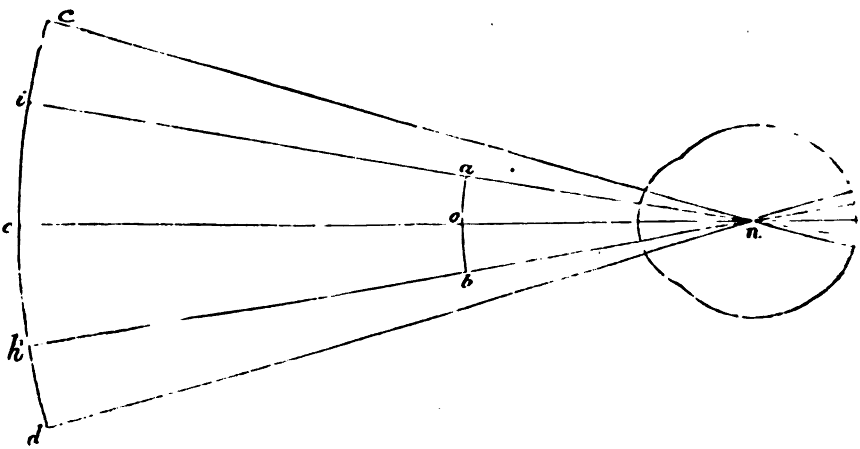
of the sight, but also on the form, colour, illumination, and lustre of the object. Bodies which are long and small generally furnish the most favourable results. And considerable advantages are offered by yellow or white on a black ground; or by glittering metallic surfaces, which

FIG. 289.



also gain by means of the irradiation we shall hereafter mention. In such cases the peculiar colour is lost before the general perception of the image ceases. In general, a healthy eye easily recognises objects the visual angle of which is from ·5′ to 1·′. Here the smallest linear extent has to the distance from the eye the proportion of 1 to 5157; so that a breadth of $\frac{1}{359}$th to $\frac{1}{333}$rd of an inch can be perceived at a distance of $9\frac{1}{2}$ inches. Assisted by the favourable circumstances just mentioned, the minimum of the visual angle may sink to a few seconds.

1518. When the apparent superficial extent of small objects is magnified by optical instruments, this is effected by an increase of their visual angle. This process may be best explained by an examination into the general arrangements of lenses and the microscope.

1519. Supposing *V W*, Fig. 290, to be a simple lens, and *A B* the small object, the latter is interposed between the lens and its focus, and not far from the latter point, while the eye is brought as close as possible to *V W*. We then get the magnified virtual image *a b*, at the distance of the natural visual range (§1472). If we imagine *A B* removed to this distance, it will obviously offer a much smaller visual angle than *a b*.

1520. The compound microscope (Fig. 291) consists of the object glass *b*, and the eye-piece *c*. The former often contains many lenses, and the latter may include a collective glass in addition to the proper eye-piece. Disregarding the complications introduced by these numerous refractile substances, the small object *a d* gives a real, inverted, and magnified image *e f*, when placed between once and twice the focal dis-

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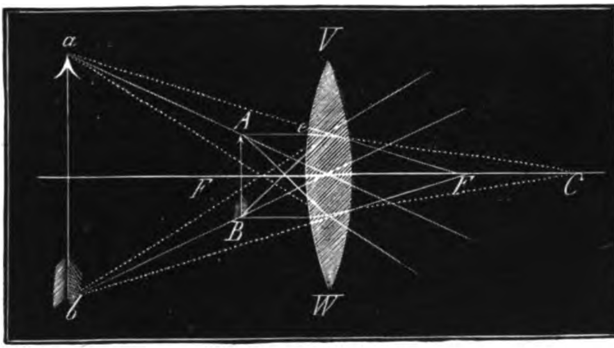
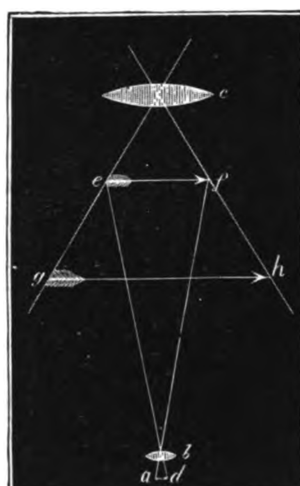
tance (§ 1472). But the eye-piece c behaves like a single lens to this image. And hence, supposing $e\,f$ ten times as great as $a\,d$, and $g\,h$ five

FIG. 290.



times as great as $e\,f$, we should get a linear magnifying power of 50 as the final result. These facts explain the great magnifying powers of the compound microscope, as well as its inversion of the image.

FIG. 291.



1521. Erect vision is a phenomenon quite as mysterious as the capacity of adjustment (§ 1493). We have already found (§ 1477) that every external object forms an inverted image on the retina. Hence it becomes a question, why objects are not perceived in this, but in the erect, position.

1522. Many have thought all explanation superfluous. The rotation of the earth is not perceived when we look at the different bodies on its surface, since we and all other masses are alike continually carried onwards; so that all relative change of place is absent. This only becomes manifest when we attempt to compare our position with that of the sun or some other star, which does not share in the movement. And, similarly, since all bodies are seen inverted, there are no relative differences which can betray the error. But this view, which has been supported by some astronomists, is opposed by the fact, that the organs of touch recognize surfaces as upright, and that the necessary movements of the eye correspond to the true, and not to the inverted, position. If we really saw things inverted, there would be an evident contradiction in these respects.

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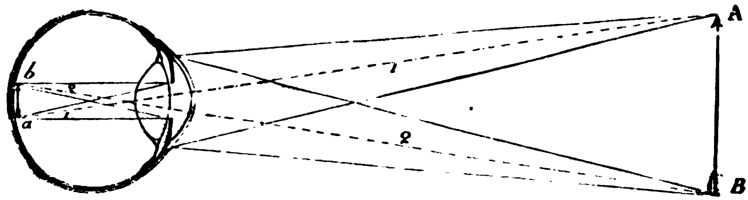
1523. Another explanation is based upon the supposition, that the points seen by us are referred externally in directions similar to those in which they reach the retina. Supposing *a B* (Fig. 292) the object, and

FIG. 292.



a b its inverted image on the retina, the rays (2) which come from *B* pass in a direction from below upwards. Now if the impression were referred outwards in the corresponding line of direction *b B*, the inversion of the image would itself form the chief cause of our perceiving it in its true position, instead of in the opposite one. This would therefore constitute a congenital faculty, of which no further explanation could be given.

1524. The subjective visual impressions seem to corroborate this view. An impression which impinges on a limited portion of the retina produces luminous images which are referred by us to the opposite side. When we press an external part of the retina, we see a luminous image in the internal segment of the visual field; and *vice versâ*.

1525. It is obvious that the supposition of a congenital faculty, the causes of which remain unknown, defers an explanation, instead of affording one. And apart from this, experience teaches us, that the determination of locality does not always depend upon the situation of the image on the retina. A man standing on his head sees the roof of an opposite house above, just as if he were in the usual upright attitude. This at least shows, that the supposed congenital faculty succumbs to the influence of the earliest acquisitions of experience. While, in treating of innervation, we shall find that other phenomena which depend on such original arrangements do not exhibit this yielding character.

1526. Many physiologists have sought an explanation in what is called the muscular sense. They suppose we gradually learn that it is necessary to direct the gaze upwards in order to see the roof of a building, and downwards to see the ground. This either renders us indifferent to the local position of the image on the retina, or it corrects our vision, supposing it originally inverted. The phenomena of subjective luminous images mentioned in § 1524 would thus represent not so much the cause, as the effect, of this education of the eyes. But many objections may be raised against this theory also. For it might be expected that until the education of the child was completed in this respect, there would be a conflict between the sight and the touch or

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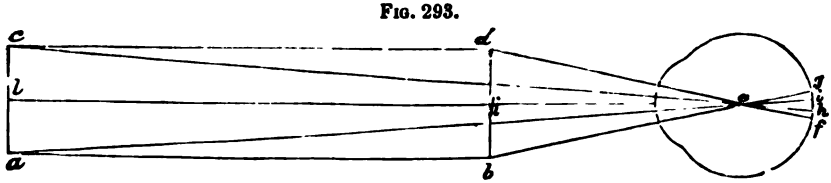
muscular sense. Experience, however, appears not to confirm this supposition. Persons who have been born blind, and afterwards obtain their sight, see objects at once in the erect position.

1527. However perfectly our organs of sight act in many respects, still in others they are very inaccurate. Our judgment of the superficial extent of any object depends immediately upon the size of its image on the retina. We notice how much is seen directly, and how much indirectly (§ 1514); we refer the several neighbouring points of the image to a certain distance, and conclude from hence the superficial extent of the luminous mass. But as we have no means of accurately measuring the distance itself, we frequently make great mistakes.

1528. Supposing *a b* and *c d* (Fig. 293) to be two parallel rows of

FIG. 293.



trees, the more remote interval *a c* will appear to us with a visual angle *c e a*, and a retinal image *i h*, smaller than *d e b* and *g f*, which correspond to the nearer interval *d b*. And since this is repeated from tree to tree, it will seem to us as if the parallel rows *a b* and *c d*, which form the avenue of trees, converged towards a point at the end *c a*. Many other phenomena may be deduced from similar causes :—such are the apparently greater steepness of a mountain-path when regarded from a distance; or the overhanging obliquity of the top of a tower, at the foot of which we are standing.

1529. The action of the organs of sight affords no direct measure of the distance or depth of a body. Hence we assist ourselves with collateral phenomena; by which, however, we are often led into errors. A body which throws more rays of light on the retina,—which is more strongly lighted, or gleams more brilliantly,—is judged to be nearer than one which does not enjoy these advantages. When no intervening objects meet our gaze, so as to afford a comparison, we refer luminous bodies to too short a distance. The giant mountains of the Alps, or birds careering over a desert or an open sea, are generally supposed to be nearer than they really are.

1530. The impression produced by a luminous object does not always coincide with the exact space and duration of its image on the retina. On the contrary, irradiation causes a local diffusion. And the endurance of the visual impression gives rise to a temporary after-effect.

1531. A bright gleaming object placed upon a black ground appears to us broader than a black one on a white ground. Although the black

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stripe which separates the two white fields in Fig. 294 is just as large as the white one between the two black surfaces, it appears to be smaller, on account of the powerful irradiation caused by the bright white. The disturbance of the excited tissues of the retina is to some extent shared by those in their neighbourhood; and the more so, the greater the brilliancy of their image, or the vital force by which they are agitated. The strength of the deception also varies with the sensibility of the retina. Hence it may not only vary in different individuals, but even in the same person at different times.

FIG. 294.

FIG. 295.

1532. The apparatus represented in Fig. 295 offers a means of expressing the quantity of irradiation as an angle of definite amount. Here we have two white fields, and two black ones. But the latter overlap the middle line *b h* by that distance which intervenes between *b h* and *a b* or *h g*. If the whole be gradually removed until *a b h g* begins to appear as a straight line on account of the irradiation of the white field, we get a right-angled triangle, of which one side is the excess of *a b* over *b h*, and the other is the distance from the eye. Hence we may calculate the angle of radiation opposite to the first of these sides. In this way Plateau obtained angles varying from 17 seconds to 1 minute 22 seconds.

1533. The endurance of an impression on the retina is due to the fact that the visual perception produced by a luminous body persists for a certain time after its removal. If a glowing coal be suspended by a wire, and rapidly whirled round in a circle, it makes the impression of a fiery ring. For although the luminous object is constantly in motion, the previous impression remains for a certain time. And if during this time such a body be made to describe an entire circle, we shall perceive a continuous and immovable fiery ring, instead of a series of separate images of flame.

1534. It is easy to see how this phenomenon may obscure the perception of movement. When a ciliated membrane is lit up by the almost

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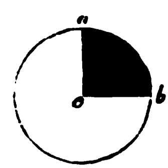
instantaneous electric spark, its several cilia appear to be standing still. While conversely, the after-image may bring before the eyes movements which ought no longer to be seen. If we look closely at a waterfall for some time, and then cast our gaze upon an uniform surface, the previous movement appears to continue in the particles now looked at.

1535. Just as every object at rest becomes invisible at a certain minuteness of the visual angle, so the same thing recurs for moving masses. The angle described by a revolving body in a given unit of time is itself dependent upon a number of collateral circumstances; such as lustre, contrast of colour, comparison with other bodies, &c. For example, it may be generally stated that a good eye can see the movement of the hand of a watch when the angle amounts to 1·5′ in the second of time; or when the distance from the eye is 2292 to 3438 times as great as the space traversed during the same period.

1536. By means of clockwork, discs cylinders or mirrors may be made to revolve with a given amount of velocity. Hence these form an important means of accurately stating spaces of time which would otherwise be indeterminable from their minuteness. We have already seen (§ 629) that an apparatus of this kind has been made use of to discover various phenomena of the pressure of the blood. And many of the questions now under consideration may also be settled by the aid of such instruments.

FIG. 296.



Supposing that the disc represented in Fig. 296 has one quadrant *a b c* black, while the remainder is white, —the duration of the impression on the retina will obviously amount to $\frac{3}{4}$ths of the time occupied by that rotation which first makes the whole appear uniform. By exchanging *a b c* for the different colours, we shall be enabled to state their influence numerically. In this way Plateau found that, with white on a black ground, the image on the retina endured 21·2 thirds of time; while yellow gave 21·3, red 20·7, and blue 19·4. When the disc was divided into a number of equal sectors which were alternately black and some definite colour, the times at which an uniform and mixed coloration came into view were 11·5 thirds for white, 11·9 for yellow, 13·9 for red, and 17·7 for blue.

1537. These phenomena were made use of by Massow to determine the photographic sensibility of the visual organs. We will suppose that the revolving disc possesses a black sector, the extent of which amounts to $\frac{1}{30}$th of the whole:—at a certain velocity of revolution, a greyish-white will be perceived. But this is less bright than those segments of the disc in which there are no black moving surfaces. The limit of sensibility will be where the eye can no longer remark any difference. The larger the surface of the dark segment, the stronger the grey appears: and

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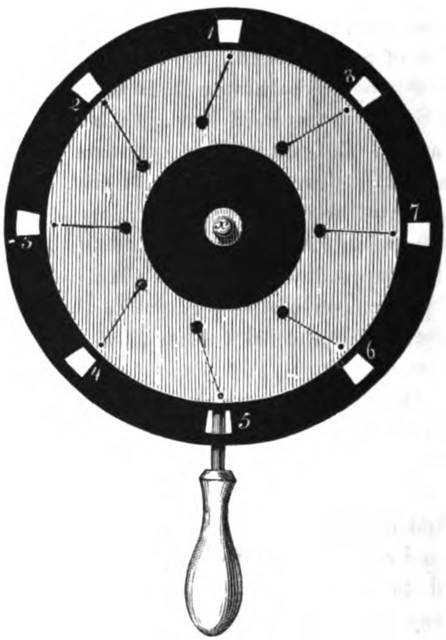
similarly, a sharper eye appreciates the difference produced by smaller black sectors. So that the fraction of the whole which these constitute will at once afford the requisite measure. In this way Masson found that it was $\frac{1}{80}$th to $\frac{1}{100}$th for healthy eyes; $\frac{1}{50}$th being the minimum for weak organs, and a fraction smaller than $\frac{1}{120}$th for very acute ones.

1538. The thaumatrope is another practical application of the endurance of impressions upon the retina. The disc represented in Fig. 297

Fig. 297.



is capable of being rotated around its centre x. It possesses a series of holes (1 to 8) which, when they pass the eye, allow it to observe any drawing placed behind them. For example, when we look at eight different positions of a swinging pendulum, as represented in Fig. 297, the after-image of the first always combines with the appearance of the second. And thus we get the total impression of the swing of such an apparatus, —or of any other movement (such as running, jumping, &c.) which the corresponding drawings are designed to afford. This apparatus, which is generally a mere optical amusement, has been used by Mueller to illustrate the appearances of undulatory movements, and by Savart to represent the forms of a jet of water.

1539. It has already been mentioned (§ 163) that the various colours differ from each other in the number of vibrations occurring in a given

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unit of time. The outermost red is in this respect to the outermost violet, as 1 to 1·6 or 1·7. Now since the octave doubles the vibrations of the fundamental note (§ 1403), it follows that we can only perceive less than an octave of the æthereal impulses, or about a sixth.

1540. Just as some persons are unable to perceive the rhythm of sonorous vibrations—*i. e.*, the peculiarities of musical altitude,—so there are others who are incapable of accurately appreciating the vibrations of the luminous æther. They therefore distinguish various colours but very imperfectly; indeed many often remain almost unknown to them. The existence of such defects gives rise to the state called Daltonism or akyanoblepsia. Red, blue, and violet—*i. e.*, the colours which are deepest in the scale of luminous intensity, and occupy the extremes of the series of vibratory numbers—are those which oftenest give rise to these defective perceptions. Where the defect is not very great, it may remain unknown for years, since the difference in the sensations may be concealed by the uniformity of our expressions. The subject of such a defect often indicates shades of colour which really appear differently to him, with the same words that are usually applied by a healthy person to other colours.

1541. The compound colours are due to an admixture of two different tints. In this way yellow and blue produce green. But on the other hand, what are called the complementary colours are those which, when united to each other, produce white light. The complementary colour which corresponds to any other may be easily found by drawing a

FIG. 298.

straight line from the compartment of the latter on the annexed circle (Fig. 298) through its centre. Thus, for instance, we find that red is opposed by bluish-green, and yellow by bluish-violet.

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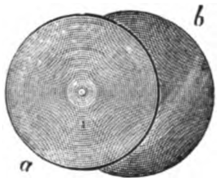
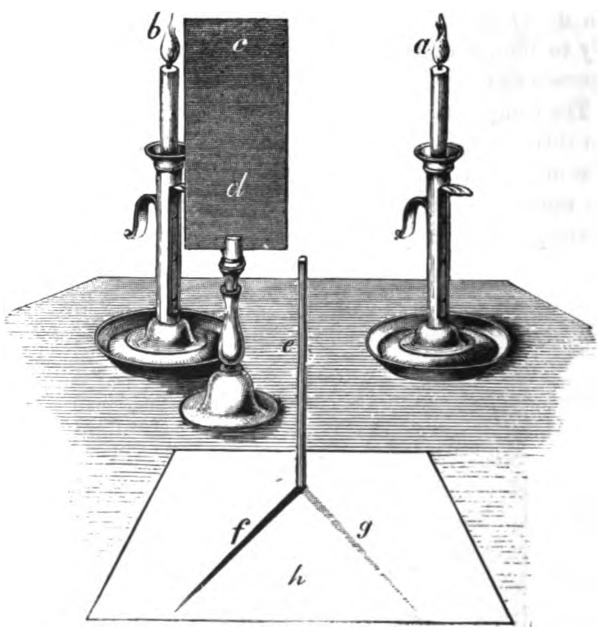
1542. Many similar appearances may often be verified in the subjective and objective phenomena of vision. When we stare at a red wafer on a bright white ground, until the eye is fatigued, and then suddenly withdraw uor gaze, we see a new circle of equal size, and of a bluish-green or complementary colour. If a red wafer (*a*, Fig. 299) be looked at for some time, and the visual axis then moved through a very small angle, we shall see a bluish-green complementary circle (*b*). In the same way white upon a black ground is succeeded by a dark image on a bright field, and *vice versâ*.

Fig. 299.



1543. The phenomena of coloured shadows are essentially identical with the preceding. Supposing that *a* and *b* (Fig. 300) are two candles, one of which *a* radiates its own light, while that of *b* passes through

Fig. 300.



a coloured glass *c d*; an upright rod *e* will give two shadows, *f* and *g*, composed of the mutual complementary colours. In this way, for example, we get yellow or orange and blue, or violet and yellowish green. The colour of one shadow is obviously due to the nature of the coloured glass; *i. e.* to a peculiar character of the objective light. While, on the other hand, the second complementary colour is subjective.

1544. When the eye has been dazzled by staring at some glittering

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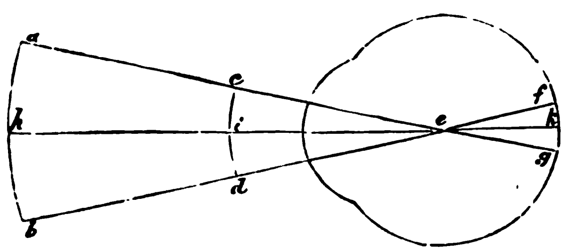
object, it sees peculiar images, which offer a succession of different colours. These phenomena are especially produced by prolonged gazing at the sun, either directly or in a mirror. Objects which are less brightly luminous give rise to similar results. The lesser fatigue they imply makes them, however, less durable. The succession in which the various colours are repeated, seems to differ in different persons.

1545. We have seen (§ 1514) that those points of a luminous body are most plainly perceived, which are mirrored upon the retina at the posterior end of the visual axis, and in its immediate neighbourhood. Those which fall outside this place gradually increase in obscurity, and finally altogether disappear. Hence all satisfactory perception is limited to an angle of a certain width at the optical centre (§ 1484). Supposing this limitary angle to be *c e d* (Fig. 301), it is obvious that the extent which can thus be looked over will increase with the distance. It will

FIG. 301.



amount to *c d* for the distance *i e*, and to *a b* for the distance *h i*. Hence while a healthy eye can only look over a fraction of a yard in its immediate neighbourhood, it can include many thousands at an unlimited distance.

1546. Those movements of the eye which depend upon its muscles (§ 1439) rotate (as it were) the perceptive surface around the centre of the organ (§ 1442). In this way the individual is spared the trouble of many adjustments which must otherwise have been effected by the various muscles of his body. The horizontal arc of movement producible by the muscles of the eye amounts to about 110°, and the perpendicular to about 100°.

1547. Where the two eyes *a* and *b* (Fig. 302) are situated laterally, as is the case in most animals, the visual curves *d g c* and *f h e*, which form the limits of possible perception, may be completely separated from each other. Under these circumstances, an object at *g* will be perceived by *a* only, and another at *h* by *b* only. But where, on the contrary, both eyes are directed forwards, the visual curves *c g d* and *e g f* (Fig. 303) will intersect each other at *g*. There is thus a central portion, the luminous points of which throw their images upon sensitive portions of both retinæ, so as to form a common visual circle.

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1548. The latter arrangement plays an important part in the visual phenomena of man and many animals. The object of vision with two eyes is not that of enabling us to perceive two different views simultaneously. It is intended to render a single observation clearer, rather than to confuse an instantaneous act by useless complications.

FIG. 302.

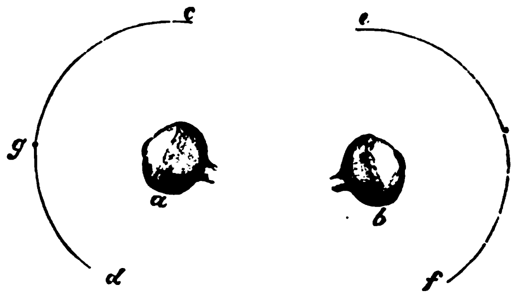
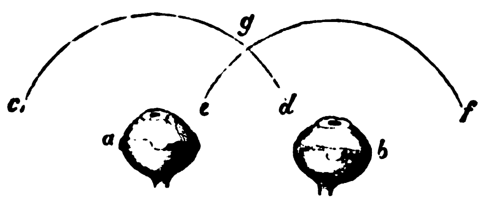


FIG. 203.



1549. Let us suppose that *y* and *z* (Fig. 304) are the two centres of the left and right eye, and *r r′* the middle line of the face, lying in the same transverse plane. If three luminous points, *r*, *e*, and *m*, be placed in the course of *r r′*, it will depend upon the position of the conducting lines prolonged from the axes of vision, which is seen single and sharply defined, and which double and obscure. If these lines pass in *e f* and *e g*, so that *w f* and *x g* correspond to the axes of vision, and if *e* be within the limits of the visual range (§ 1489), it will be seen perfectly clear and single; while *r* and *m* will appear as faint double images. This law is best illustrated by three threads or pins, fixed upon a suitable line of sight. A person whose eyes are sensitive need only look fixedly on one of the two index fingers in a line behind each other, to see the second doubled.

1550. The point *e* lies in the median line *r r′*. The conducting lines *e f* and *e g* have therefore the same length. Here both eyes are acting for the same distance. But since the range of vision includes all that lies between the maximum and minimum distance (§ 1489), a lateral point *p* can be seen distinct and single, so long as *p g* does not exceed the distance of the farthest, or *p f* that of the nearest, point.

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1551. It is obvious that the limits within which distinct and single vision is attainable by two eyes are essentially determined by the original length of the visual range (§ 1489), aided by the capacity of adjustment (§ 1488), and by the non-spherical form of the lens (§ 1483). It is not a surface with which we are here concerned, but a definite region, which has all three of the dimensions of space, although its mathematical form can rarely be given. But many have sought to simplify the phenomena we are now considering by the aid of numerous assumptions, which have little or no approximation to the truth.

FIG. 304.

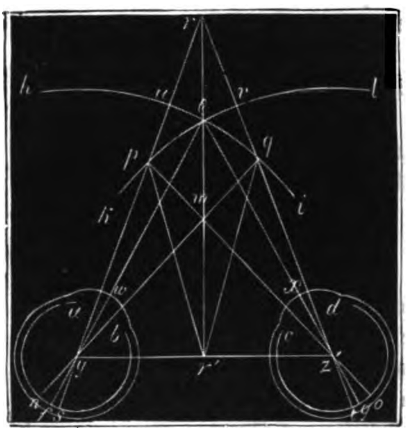
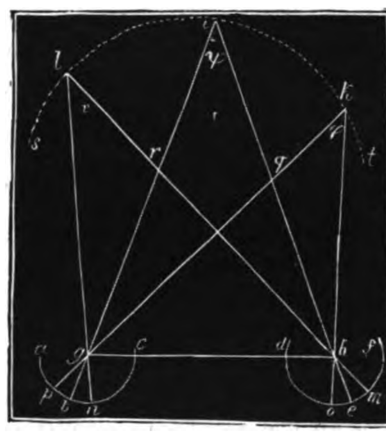


FIG. 305.



1552. We will suppose l, i, and k (Fig. 305) to be three points, which are seen single and distinct by both eyes. If the external angles of direction, x, ψ, φ,—or the angles formed by the conducting lines,—are equal to each other, the line of the visual field $s\ l\ i\ k\ t$ must be a segment of a circle. But if, on the other hand, the proportions are such, that the sum of every two conducting lines reckoned from the centre of rotation forms a constant magnitude,—that is, if $gl+lh=gi+ih=gk+kh=C$,—$s\ l\ i\ k\ t$ must be an ellipse, having its foci in g and h. Many recent inquirers have simply assumed that the line of the field of vision corresponds to the arc of a circle, an arc which might obviously be regarded as a straight line at an unlimited distance. But it is evident that this assumption, which has an incorrect—or at least an unsafe—basis, can lead to no further results of a trustworthy character.

1553. Let us imagine that $l\ i\ k$ (Fig. 305) represents a portion of that limit within which we can see objects singly and distinctly with two eyes (§ 1549), when the prolonged axes of vision intersect each other in i. The posterior extremities of these axes are thus at b and e. The point k, which is also seen single, is mirrored in p and o; *i.e.* externally

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to the posterior extremity (b) of the axis of vision in the left eye, and internally to it (e) in the right eye. A similar contrariety obtains with respect to l, save that the situation is reversed for each of the two eyes. Hence p and o, or n and m, are said to be identical or corresponding portions of the retina, because the similarity of the images pourtrayed on them causes the impression to be single.

1554. Recurring to the facts illustrated in § 1549, the point e (Fig. 304), which lies within the limits of the visual range, appears single when it is intersected by the conducting lines $e f$ and $e g$. Hence f and g are the posterior extremities of the axes of vision. The point m, which is seen double, is mirrored in n and o: and the point r, which is also seen double, in s and t. That is, each is seen in both eyes either external or internal to the posterior extremities (f and g) of the two axes of vision ($w f$ and $x g$). So that n and o, or s and t, are non-identical or non-corresponding points of the retina.

It is evident that the act of squinting (§ 1450) may lead to the perception of double images, since the deviation of one eye allows the image to fall upon a non-identical point. Hence such persons often habitually disregard the perception of the affected eye. It therefore gradually becomes blunted.

1555. The simplest conditions would be those which assume that the line of the visual circuit $s\,l\,i\,k\,t$ (Fig. 305) is an arc of a mathematical circle, and each eye a globe rotating around its centre g or h. Here the corresponding portions of the retina p and o, or n and m, would lie at equal distances from the posterior extremities of the axes of vision; and would only occupy opposite places.

1556. A simple experiment will convince us that each eye in the first instance communicates its view to the brain, and that it is only here they are combined into one. When we hold a tube of proper length before each eye, keeping their axes nearly parallel, we see the two openings separate. If we now make them gradually converge, their openings will constantly approach each other. Supposing the length of the tubes not to exceed the limits of the visual range, we shall at last find a position in which we see only a single median circle of exit. The centres of both circular apertures then lie in the course of the conducting lines which cross each other at a point corresponding to the visual range. The other points fall upon corresponding parts of the retina. The single view is thus explained from the facts previously mentioned. If we now provide the opening of one tube with a yellow glass, and that of the other with a blue one, the single orifice of exit will scarcely ever appear of the intermediate green colour. It is seen sometimes yellow, and sometimes blue: or one of these colours predominates in one place, and the other in another. This phenomenon is sometimes called the contention of the two eyes, or of the two visual fields. The numerous

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and variable appearances which are thus evoked depend upon the luminous intensity, the coloration, the distance, the adjustment of the eye, and the amount of attention given by the observer.

1557. We have already (§ 1529) remarked that the eye can judge far more accurately of surface than of depth. But the perception of corporeity or solidity implies a recognition of all three dimensions of space. Hence certain collateral conditions are required for the assistance of the eye. And the organic apparatus itself is often aided by the lessons of experience in bringing about the desired effects.

1558. It is obvious that even one eye is capable of recognizing the solidity of a body. A mere drawing of a pentagonal dodecahedron (Fig. 306) appears to be solid; and the more plainly so, the closer we approach the cornea to the figure, so as to withhold all lateral impressions. We have but to look at Fig. 306 through a paper tube to obtain a direct confirmation of this latter statement.

1559. On looking at two corresponding drawings of a relief with both eyes, the impression of solidity becomes much greater when the similar points of each excite corresponding portions of the retina. The

FIG. 306.

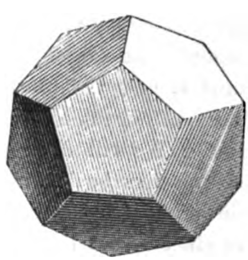

FIG. 307.

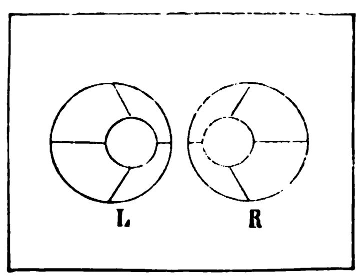

FIG. 308.

stereoscope invented by Wheatstone thus gives rise to a series of very peculiar phenomena. The more important of these may be explained with the instrument constructed by Gerber.

1560. Supposing a short cone of wire set up at a proper distance in the visual range, and exactly in the middle before both eyes, the left alone would see it as L, Fig. 307, and the right as R. Such double drawings of suitable objects are made use of in stereoscopic observations.

The apparatus represented in Fig. 308 consists of a box which can be shortened or lengthened to suit differences of the visual range. The anterior margin has an excavation *b* for the nose, above which are two holes for the eyes. The drawing represented in Fig. 307 is applied above the latter: so that its two figures are reflected in a double mirror, which is fixed against the posterior wall, and consists of two surfaces, that either converge or diverge at a very obtuse angle. Under

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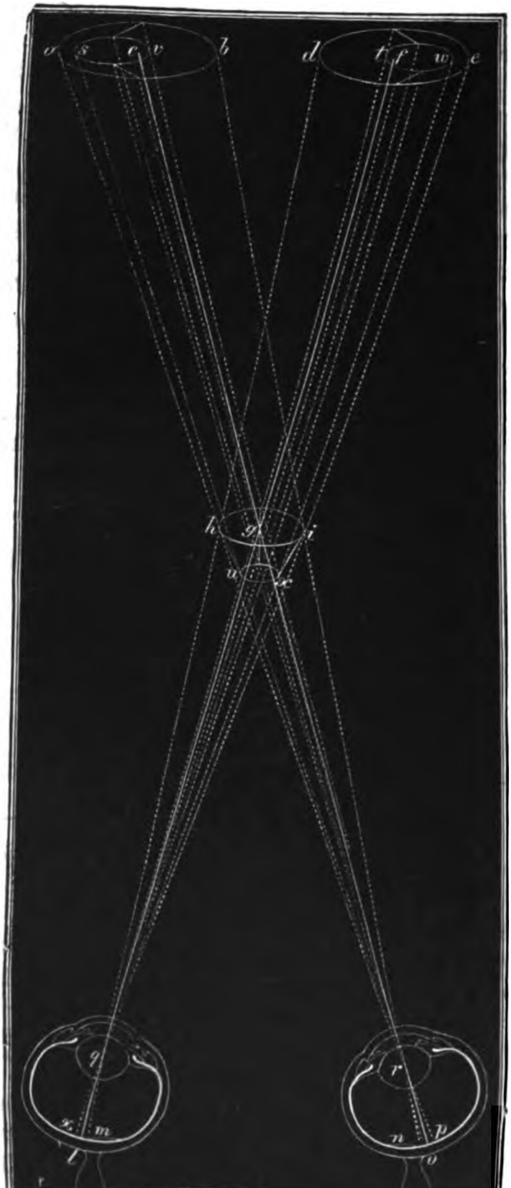
these circumstances, each of the two drawings falls upon one eye. And if the distance be so selected that their similar parts strike upon corresponding portions of the retina, we shall see a median and perfectly solid cone of wire. The two kinds of mirror above mentioned give rise to contrary views: the truncated apex of the cone being correspondingly turned to or from the spectator.

Fig. 309.



1561. The circumstances upon which this experiment is based may be further elucidated by Fig. 309. For the sake of simplicity we will disregard the interposed mirror, and the phenomena of reflection it produces. We will therefore assume that the drawings lie immediately in front of the eye, but have the same relations as their reflected images, each of which sends its rays to the requisite part of the retina of the corresponding eye. Supposing that the prolonged axes of vision *c o* and *f l* impinge upon the two centres of the greater circles *c* and *f*, these are perceived as a single point *g* at the place where the conducting lines *co* and *fl* intersect each other. But *a* has the line of direction *a p*, and *d* that of *d m*; and both meet identical places of the retina *m* and *p*. Hence they also

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are seen single at the intermediate point *h*: and, for the same reason, *b* and *e* appear at *i*. Since this is repeated for every point, we get the single circle *h i*, having *g* as its centre. And applying the same construction to the smaller circle, we shall also find a median circle; which will be before or behind that of the base, according as the eye perceives the single drawing designed for that effect, or the opposite one. The intermediate lines give rise, point by point, to corresponding lateral ones. In this way the view in space of either truncated cone *h i x u* may be constructed geometrically.

1562. It is obvious that this explanation is open to all the objections which can be brought against the assumption of identical points in the retina of the globular eye. In spite of this, however, it clearly shows, that some unknown arrangement obliges the views afforded by corresponding images on the retina to be referred to that portion of space in which the conducting lines intersect each other. We are thus enabled directly to recognize that solidity, which cannot easily be explained in a geometrical manner.

1563. If the ranges of vision, and the influence of close observation, remained limited to a single place, or even to the intersection of the conducting lines, the other parts of the solid cone would be less distinctly perceived. Careful examination teaches that this really is the case. And something similar to this occurs in the perception of solid objects themselves.

1564. We have seen (§ 1556) that the contention of the two visual fields generally affects impressions of colour. If an ordinary colour be allowed to fall upon the retina of one eye, and its complementary colour upon that of the other, we scarcely ever obtain simple white. But this unsuccessful result only depends on the fact, that the most careful selection rarely fulfils all the conditions necessary to a perfect complement. On making use of the complementary colours produced by polarized light (§ 175) or coloured shadows (§ 1543), we shall be more successful. The white then seen teaches us that there is an union of the views taken by both eyes, not only as regards their position in space, but also their undulatory rhythm. The two complementary colours are so intimately united that we are unable to perceive any decided rhythm; *i.e.*, any special colour.

1565. Just as the coloration (§ 161) of the eye is distinctly seen in many artificial experiments (§ 1511), while in ordinary vision it escapes notice,—so something similar occurs in many of those subjective phenomena that necessarily result from the way in which the various lenses and the retina are arranged in the eye. While others, which depend upon abnormal conditions, may be distinctly seen under ordinary circumstances.

1566. When a man whose eye possesses the necessary sensibility looks at the grey sky through a Nicol's prism (Fig. 33, p. 58), he first sees

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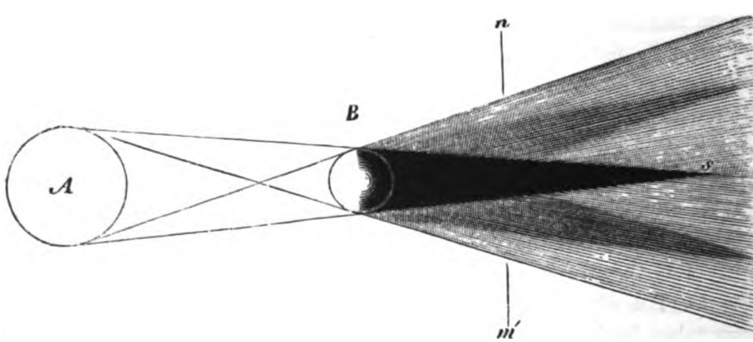
two yellow* tufts (Tab. I. Fig. 13, *a*, *b*), which correspond to the long diameter of its transverse section. These are sometimes named the tufts of Haidinger. In addition to this, sensitive eyes remark two violet† pencils, which correspond to the shorter diagonal (Tab. I. Fig. 13, *c*, *d*).

1567. Many persons do not even require such a prism in order to perceive these tufts. Others scarcely ever see them, whether they make use of this optical instrument, or of another apparatus, the dichroscopic lens. Habit seems to exercise a great influence in this respect. At least the author can see these appearances (Tab. I. Fig. 13) much plainer than he could some years ago. Continual efforts have enabled him to dispense with the prism, and yet sometimes see the tufts.

1568. The yellow tufts take the same direction as the vibrations of the extraordinary rays (§ 170) which traverse the prism. Hence with the aid of this phenomenon we may at once ascertain the plane of polarization of other polarizing bodies. This subjective perception is caused by the polarizing effects producible by the various stratified refractile bodies of the eye. The yellow and bluish violet are complementary colours of polarization (§ 175).

1569. If *A* (Fig. 310) be a luminous, and *B* an opaque body, the latter will obstruct the progress of a given number of rays of light. We thus

FIG. 310.



get the nucleus of shadow *B s*, and the half-shadows which lie outside it. The closer the screen *n m′* approaches the opaque body *B*, the greater will be the space which this shadow will claim.

1570. Similar effects are necessarily produced by opaque structures that occupy the lenses of the eye. Here the retina plays the part of the screen *n m′*. Hence the nearer these opacities lie to this nervous coat, the stronger will be the nucleus of shadow which they cast, and the more effectual the darkening of a definite region of the visual

* The printing in colours which has here been made use of renders it quite impossible to exhibit these colours as faint as they really are.

† These also have too deep a colour in the figure.

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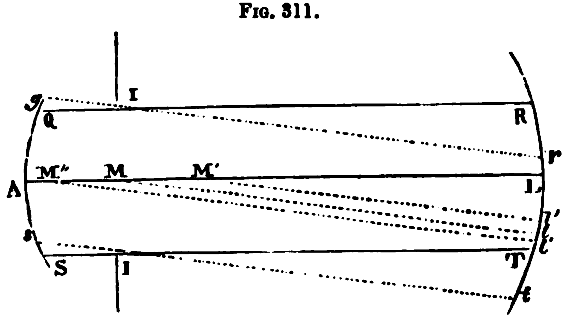
field. Extensive opacity of the cornea (such as occurs in staphyloma) or obscurities of the crystalline lens (like those which form the cause of cataract) produce blindness in this indirect way. But the retina may notwithstanding maintain its powers for years.

1571. Many of these entoptic appearances,—the greater part of which are usually designated by the name of "muscæ volitantes,"—depend solely upon such shadowings. Others are due to small structures which occupy the lenses of the eye, and reflect the light. But some of them maintain their position under all circumstances; while others change it, either spontaneously, or under the influence of the movements of the eye. Hence such entoptic substances are immediately divisible into fixed and immovable.

1572. It is obvious that both the fixed entoptic figures, and those dark specks of the visual field which depend upon local paralysis of the retina, will be alike capable of offering certain alterations of position, dependent upon the movements of the globe. The requisite condition for the appearance of many of these entoptic bodies is obtained by looking at the grey sky—or any other distant and uniformly-lighted surface—through a small opening in a screen. The pencils of the parallel rays of light which impinge upon the cornea then pass through the pupil, to illuminate a corresponding part of the retina. Now, supposing Q A S (Fig. 311) to be the cornea, I I the aperture of the pupil, and R t the retina, it is

FIG. 311.



upon the position of the latter that the site of the illuminated circle will depend. If the axis of vision lie in A L, and if there be three equal points of shadow in its course, M, M′, and M″, they will only cast one shadow in L. But if the gaze be directed upwards, so that M L is changed into M l, we shall get three different shadows: M, which lies in the plane of the pupil, itself appears at l, M′ above in l', and M″ below in l''. Hence M′ has undergone a corresponding, but M″ an opposite, change of place. Other circumstances being equal, the amount of this displacement depends upon the distance of the shadowing bodies from the retina. Listing has attempted to render this phenomenon a means of determining

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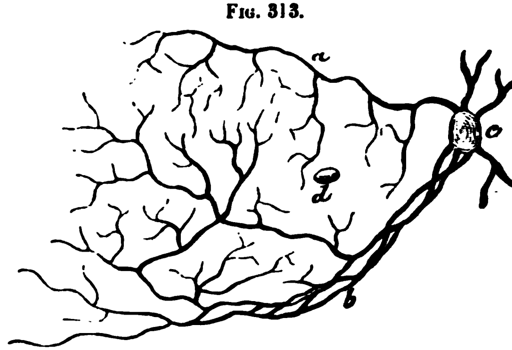
the site of small entoptic bodies. Brewster and Donders made use of two small apertures, so as to produce double images, from the mutual distance of which they deduced the situation of the bodies themselves.

1573. Small streaks of lachrymal mucus sometimes run down the outer surface of the cornea, and give rise to appearances which resemble those indicated at 2 (Fig. 312). If we look for some time through a narrow fissure or a small aperture at a highly illuminated background, or if the eye be fatigued with microscopic researches, we may remark a row of threads, a mosaic of granules, a number of roundish corpuscles (1 Fig. 312), a string of pearls, or the like. The shadowing substances upon which these phenomena depend have been referred to a variety of situations—to the aqueous humour, the lens, the vitreous body, the granular layer of the retina, and the membrana Jacobi. Those seen by every healthy eye are probably caused by parts which lie very near to the retina—if not in it.

FIG. 312.

FIG. 313.



1574. The vessels which penetrate the optic nerve, and are distributed on the inner surface of the retina (Tab. I. Fig. XIV.), also appear in the subjective field of vision. On closing one eye, and staring with the other at the black background of a dark room, while the flame of a candle is moved to and fro as close as possible to the eyelids, we get an appearance something like that of Fig. 313. Here *c* corresponds to the entry of the optic nerve, and *d* to the posterior extremity of the visual axis. The images of the vessels *a* and *b* lie on the opposite side to the vascular tubes by which they are produced. Since they are referred outwards (§ 1545), they appear, like other entoptic structures, more or less magnified.

1575. Dark bodies which lie directly on the retina,—such as effusions of blood, deposits of pigment, and the like,—necessarily cause permanent gaps in the field of vision. But while these effects are only exceptional and morbid, there is a certain part of the indirect field of vision (§ 1514), where perception is always impossible. This is easily shown by the experiment of Mariotte.

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1576. For example, if the visual axis of the left eye be directed straight upon *b* (Fig. 314) we shall soon find a distance, in which *a* is no longer perceived, while *c* is seen as an indistinct and cloudy image in the indirect field of vision. So that there is a portion of the retina which,

FIG. 314.

although lying within the limits of distinct vision (§ 1513), is blind for all purposes of objective perception. A closer examination shows that this gap in the visual field lies from 13° to 17½° outside the visual axis. Its images will therefore come into contact with the retina at a corresponding distance internal to the posterior extremity of the axis of vision. But this is exactly the place where this membrane is entered by the optic nerve.

1577. Many have stated that the whole region penetrated by the optic nerve is insensible, on account of its not possessing all the nervous elements required for vision. Others have explained Mariotte's experiment more simply, as due to the fact that the vessels which pass through the middle of the optic nerve at its entrance (Tab. I. Fig. 14) cause a gap, where the conditions necessary for perception must be absent.

Here the circumstances which prevent an exact calculation of the size of the images on the retina (§ 1483), render all absolute proof impossible. Besides, in the living eye, we can not determine anything but the distance of this blind part of the retina from the posterior extremity of the visual axis. We have never yet been able to control the corresponding distances of the several parts of the retina in the dead body of the same individual.

Confining ourselves to the measurements ordinarily assumed, it would follow that this inactive region of the retina only corresponds to the place where the vessels penetrate. It must, however, be remembered, that proportions not quite corresponding with this estimate have been observed in the eyes of some suicides.

1578. The subjective field of vision sometimes presents sparkling points of light, moveable images produced by circulating blood-corpuscles, beautiful rhomboidal figures, coloured streaks, and various patches of shadow, &c. Pressure on a certain part of the retina leads to fiery images and sparks, which are obviously unseen by any one but the person whose eye is thus treated. A rush of blood towards the eyes, the optic nerves, or the corresponding parts of the brain, frequently produces various phenomena of light and colour. The passage of a galvanic current through the head excites the eye much more readily than the ear, or the organ of smell. Under such circumstances we see fiery images; having colours which are complementary to each other

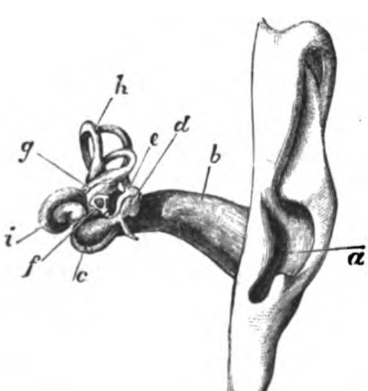
at the closing and opening of the circuit. When all foreign light is excluded, these impressions become much more distinct.

1579. *Hearing.* — One part of those waves of sound (§ 156) which impinge upon the outer ear (*a*, Fig. 315), penetrates the cavity *b*. Another part is reflected. The concussion is at the same time propagated through the solid tissues towards the auditory canal *b*, and from thence passes onwards. And many of the reflected rays of sound fall back again into the space bounded by *b*, so as not to be entirely lost to the ear.

1580. Most of the mammalia possess a simple external ear, the cornet shape of which very much resembles that of a hearing-trumpet. Numerous strong muscles move it in different directions, and thus facilitate the entry of the rays of sound. The peculiar form of the human ear can scarcely be explained. At present we do not know the cause of its strange shape, and its numerous elevations and depressions. It is certain that its irregularities are not so arranged as to reflect all the rays of sound into the external auditory canal. Hence it appears to be rather adapted to the vibrations proper to these parts themselves,—or to the easy reception, the strong concussion, and the peculiar clang, of their sounds. It has also a much smaller extent of movement in man than in most of the mammalia. Indeed, in many persons, volition has no appreciable influence in this respect. And although others are able to move the ear in one or more directions, yet this movement is scarcely ever made use of in the act of hearing itself.

1581. The loss of the external ear only so far disturbs the sense of hearing, as to diminish the acuteness of perception. The various notes (§ 1403) can still be perfectly distinguished. Buchanan finds that the angle which the ear forms with the head exercises a remarkable influence on the auditory sensibility. An angle of 25° to 45° is the most favourable: while one of less than 15° is injurious.

FIG. 315.



1582. The external auditory canal (*b*, Fig. 315) propagates the entering waves of sound; either immediately, or by reflection. It holds them together, as it were; and may assist to strengthen them by resonance (§ 1404). Its walls are also capable of vibrating, and of propagating this disturbance to the internal structures of the ear. The fatty covering formed by the wax of the ear has been supposed to facilitate the perception of distant sounds. But when this substance is aggregated, in the form of lumps which occupy

the auditory canal, it produces a mechanical obstacle which injures the sensibility of sound.

1583. The tympanum or drum of the ear (*c*, Fig. 315), is a membranous partition, which is applied to the deepest extremity of the auditory canal, and the tension of which easily permits corresponding vibrations. If it be uniformly strewed over with some very fine powder, acoustic figures may be produced on it, as on any other extended membrane.

1584. The space behind the tympanum, or the tympanic cavity, contains the three auditory bones (or *ossicula auditûs*);—the *malleus* or hammer *m* (Fig. 316), the *incus* or anvil *o*, and the *stapes* or stirrup *t*. In the adult, a minute bone called the lenticular bone, *l*, is immoveably connected with the long process of the incus. Special articulations unite these auditory bones to each other. This arrangement allows of small movements, which exercise a remarkable influence upon the mechanism of hearing.

Fig. 316.

The annexed woodcut (Fig. 317), represents a magnified view of these structures *in situ*. The head *d* of the malleus rests in the excavated

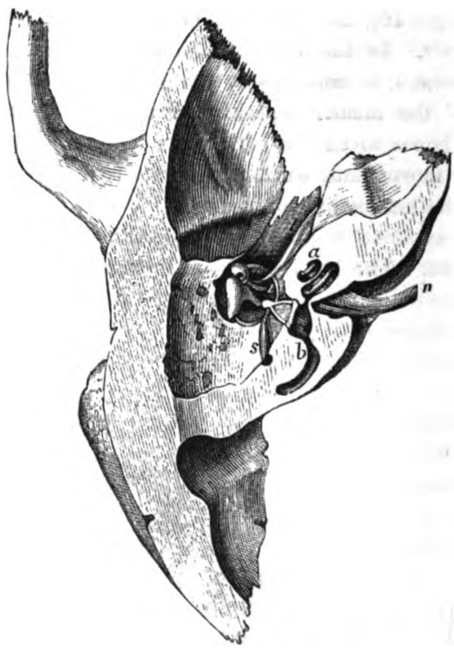
Fig. 317.

articular surface of the body *e* of the incus, while the long process of this latter is united to the stapes *f*. The long process of the malleus *d* is united to the tympanum which bounds the auditory canal *a*. The

oval aperture that bounds the foot-piece of the stapes leads to the vestibule, which contains a portion of the auditory nerve. The chain of the auditory bones is thus interposed as a solid and articulate piece, connecting the tympanum with the innermost and most important parts of the organ of hearing.

1585. The mutual position of the auditory bones is capable of being more or less altered by special muscles. The situation of the parts as seen in the recent state is seen in Fig. 318. The malleus, *t*, has a

FIG. 318.



muscle called the internus mallei, or tensor tympani, *l*, which draws the handle of the malleus inwards, and thus indirectly stretches the tympanum. A second muscle, the laxator tympani, is but rarely discernible. Finally, the stapes has a special muscle, the stapedius, *s*, the action of which presses the lower part of the foot-piece (*f*, Fig. 317) into the foramen ovale, and perhaps at the same time opposes the tensor tympani or internus mallei (*l*, Fig. 318).

1586. That varying tension of the tympanum which is inducible by the muscle last named, may be conjectured to subserve certain acoustic purposes. Some have supposed that when powerful sounds require to be damped, a greater tension is produced. But whatever may be the intrinsic probability of this view, still it has not hitherto been sufficiently confirmed by those direct observations which have been made in

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suitable cases on the living subject. Powerful tension of the tympanum seems to injure the perception of deep sounds; while, on the contrary, it favours that of high ones.

1587. A tense elastic membrane takes up the sonorous vibrations of the air more easily than a massive and thick body. It also communicates them better to neighbouring solid textures. This at once explains why the tympanum is interposed between the air of the tympanic cavity and its ossicles on the one hand, and the external auditory canal on the other.

1588. The sonorous undulations of the tympanum are propagated onwards along the chain of auditory ossicles. These again render it easier for the tympanum to vibrate in concert with sounds which differ from its own. But at present we are not acquainted with all the acoustic reasons for their being articulated with each other. Neither the presence of their respective muscles (§ 1585), nor the possibility of their giving way under powerful curved undulations, constitute a complete explanation.

1589. The loss of the tympanum and the auditory bones does not destroy all possibility of hearing. Hence, however important their aid, these structures are not essential to the perception of sound. The proximate cause of this phenomenon will be rendered evident by facts hereafter to be mentioned.

1590. The cavity of the tympanum, which encloses the auditory bones (Fig. 318), communicates by its side with the Eustachian tube (*b*, Fig. 317) which opens free into the pharynx (*f*, Fig. 128, p. 232). This arrangement has the direct effect of preventing the tympanum from being pressed too much outwards. For the air of the tympanic cavity generally has a higher temperature than that of the external auditory canal. In addition to this, it is saturated with watery vapour for its temperature. So that, if it were not allowed a free exit, it would stretch the elastic tympanum outwards.

1591. But it is evident that the same purpose might be effected by a simple aperture, which would also carry off the mucus that is sparingly secreted by the tympanic cavity. It is therefore to special collateral causes that we must attribute the addition of this tube,—which has a peculiar curved form, is partly osseous, partly cartilaginous, and possesses a ciliated internal surface (§ 1196).

1592. Some have supposed that the Eustachian tubes afford a clearer perception of those sonorous undulations which pass along the cavity of the pharynx — and especially of the sounds of a person's own voice. This opinion, however, is not confirmed by examination. Many, with Henle and Mueller, regard it as an apparatus which strengthens sound by resonance, and increases its clang. But it remains for more accurate researches to establish whether its column of air is capable of adding the sound of its own note:—a circumstance which would indeed rather

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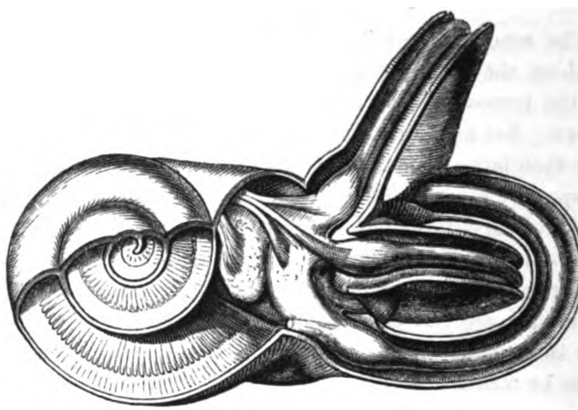
disturb, than further, the effect. Be that as it may, it is at any rate certain that obstructions of the Eustachian tubes by mucus or exsudations greatly damages the sense of hearing, and often compels the surgeon to its removal by means of the catheter.

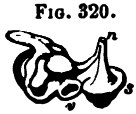
1593. The labyrinth consists of the vestibule *g* (Fig. 315, p. 476), the three semicircular canals *h*, and the cochlea *i*. All these are shown magnified (and partly laid open) by Fig. 319. Here the membranous

FIG. 319.



vestibule and the membranous semicircular canals are seen to be separated from the corresponding osseous walls by a space which contains a fluid, the perilymph. One portion of the auditory nerve branches in the vestibule, and in the inferior dilated extremities or ampullæ of the semicircular canals. The cochlea, which is half laid open, permits us to see how the spinal lamina, on which another part of the auditory nerve is distributed, rises by 2½ windings in its interior. The way in which the several chief divisions of the auditory nerve (*n*) pass to the vestibule (*v*) and the cochlea (*s*) may be illustrated by Fig. 320. The interior of all three chief segments of the membranous labyrinth encloses a fluid, the endolymph.

FIG. 320.



1594. Since the foot-piece of the stapes occupies the foramen ovale (*f*, Fig. 317, p. 477),—while the space around it is filled up by a tense membrane,—its vibrations are at once communicated to the endolymph of the vestibule. The undulations of fluid thus excited impinge upon those fibres of the auditory nerve which are distributed in the interior of this segment of the labyrinth, and in the ampullæ of the semicircular canals. The *otoconia* or ear-sand of the vestibule, which consists of microscopic crystal of carbonate of line, increases the impulses, and thus sustains the auditory impression.

1595. The exact use of the semicircular canals is at present unknown.

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But it is supposed that the undulations which enter them at one end, pass through their whole extent, and return to the vestibule. This perhaps strengthens the sound, facilitates the repetition (and hence the perception) of the impulses, and prolongs the impression. But at present we cannot state the object of the various irregularities which occupy the interior of the vestibule, or say why the superior and posterior semicircular canals unite into a single tube (Fig. 320.)

1596. The foramen ovale (*f*, Fig. 317, p. 477) is not the only opening that leads from the labyrinth into the tympanic cavity. There is a second, the foramen rotundum (*o*), over which is stretched an elastic membrane, the secondary tympanum. According to Weber, as soon as the foot-piece of the stapes is pressed into the bottom of the foramen ovale (*f*), this membrane yields, and thus allows the endolymph to evade the pressure. Besides this, it must also be thrown into vibration by those waves of air which are excited by the vibrating walls of the tympanic cavity and tympanum. And its connection with the inferior cochlear canal (or *scala tympani*) seems to indicate a special relation to this part of the labyrinth.

1597. The dense substance of the bones of the head is a good conductor of the sonorous undulations. The latter are therefore conveyed to the cochlea, which is connected with these bones, more easily than to the vestibule (§ 1593), which is surrounded by the perilymph. It has therefore been supposed that such sonorous undulations are chiefly received by the cochlea. While those vibrations which are propagated through the ossicles are believed to enter more directly and forcibly into the endolymph of the vestibule. At present, however, we are ignorant what use this twofold arrangement subserves. Our knowledge of acoustics is so deficient, that we are quite unable to explain why the organs of hearing are constructed of such very heterogeneous structures.

1598. The intensity of the impulses that impinge upon the auditory nerve determines the strength—and their rhythm, the height—of the sensation of sound. But we are just as unable to give a detailed explanation of the mechanism by means of which we appreciate the clang of a sound, as of the molecular relations which originally determine its production.

1599. The fact that auditory perception is limited to those sounds which possess a certain strength forms a parallel to the photometric sensibility of the eye (§ 1537). While the capacity of the ear to appreciate the height of notes corresponds to the distinction of colours by the eye. Savart concluded from his experiments that the lowest note perceptible by the human ear, is composed of 14 to 16 vibrations in the second, and the highest of 64000. Despretz places these limits at 32 and 73000 respectively. But these phenomena do not warrant our concluding that the auditory nerve is in itself unable to appre-

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ciate the rhythm produced by more or fewer vibrations. Future research must determine whether there is a complete parallel in this respect with the perception of colour (§ 1540).

1600. Just as the eye can only directly recognize differences in the rhythm of colours, so the ear cannot count the number of vibrations. It rather judges of the whole as of one direct impression. The delicacy with which two neighbouring notes can be distinguished from each other varies greatly in different individuals. Persons who are devoid of a musical ear make extraordinary mistakes in this respect. While, according to Seebeck, more gifted individuals can plainly recognize the difference between two notes, the vibrations of which only differ by $\frac{1}{1200}$th of their whole number.

1601. And just as the perception of the height of a note is due to its rhythm, so the musical relations of a sound are based upon the mutual proportions of impulses which arise either simultaneously, or in rapid succession to each other. The octaves, which proceed in geometrical progression with the exponent of 2, sound like heterogeneous repetitions of corresponding notes. The consonance or dissonance of other notes when sounded together, depends upon the nature of their intervals. If these are in progression, we get an agreeable impression; if they are not, a disagreeable one.

1602. The number of vibrations of the fundamental *c* and the fifth *g* have to each other the proportions of 1 to $\frac{3}{2}$, or of 2 to 3, and are hence in progression. In like manner we get 1 to $\frac{4}{3}$, or 3 to 4, for the fundamental note and the fourth; and 1 to $\frac{5}{4}$, or 4 to 5, for the former and the third (§ 1403). All these combinations of notes harmonize with each other; while, on the contrary, the second, *d*, and the seventh, *b*, give $\frac{9}{8}$ to $\frac{15}{8}$, or 3 to 5. Hence they lead to a dissonant impression. While the harmonic triple sound formed by combining the fundamental note, the third, and the fifth, is composed of 1, $\frac{5}{4}$, and $\frac{3}{2}$;—a proportion which is equivalent to the numbers 4, 5, and 6.

1603. A practised ear can appreciate two different notes which are sounding simultaneously. Here one of the impressions is probably perceived somewhat sooner than the other. But when two notes having nearly the same number of vibrations occur simultaneously, the sound is heard alternately swelling and receding. The cause of this pulsation may be explained by the diagram (Fig. 321). Supposing the two thin lines to represent the waves of the two notes, they will be strengthened by their coincidence at *f*, *d*, *b*, and *a*; and weakened by their interference at *c*. Hence the variations of strength may be represented by the relation of the thick line to the straight one.

1604. The several pulsations produced by this fluttering follow each other with greater rapidity, the more nearly the two notes correspond in the number of their vibrations. When they are repeated with great

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velocity they give rise to the impression of a third note, which is called a note of combination.*

1605. The ear distinguishes relations to space much less perfectly than the eye. It cannot in any way recognize the distribution of surface. Extent in depth, or distance, is chiefly measured by the strength of the sound; and direction, by the manner of the impression. In the latter case one ear has so far the advantage, that the sonorous undulations which directly impinge upon it, are communicated more faintly to the second. According to Seebeck, it would seem that impressions which agitate both organs are not reduced to a medium perception, like the images of corresponding parts of the retina (§ 1553).

FIG. 321.

1606. The after-sound which is frequently observed may be either objective or subjective. The first case supposes the vibrations to be repeated for some time. While in the latter, there is an effect upon the nervous part of the auditory apparatus, similar to that which causes the endurance of the image upon the retina of the eye, (§ 1533). The time occupied by this subjective after-sound has not yet been exactly estimated.

1607. It is obvious that lesions of the acoustic nerve, or of the whole labyrinth, will necessarily lead to complete deafness (§ 1432). But there are some persons who, though hard of hearing, can accurately follow a discourse, when they take one end of a stick between their hands, and place the other on a solid body which is in close proximity to the speaker. Recalling the suppositions mentioned in § 1597, we might conjecture that here the vestibule, but not the cochlea, has become inactive.

1608. Subjective auditory sensations proceed from two causes:—from changes which attack the conducting parts of the inner ear; and from influences which act directly upon the auditory nerve. Many persons can voluntarily contract the internus mallei muscle (§ 1585), so as to produce a tolerably loud crack, which is audible to other persons. When an unusual quantity of air is driven into the tympanic cavity, we hear a peculiar noise, which also depends upon the altered tension of the tympanum, and its further effects. The singing in the ear which is fre-

* In the text this is also designated the note of Tartini.

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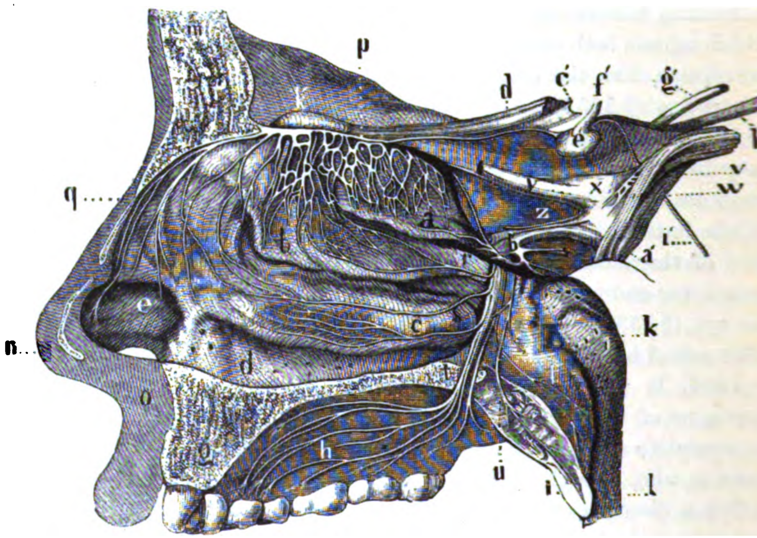
quently met with in congestion of the head,—as well as in prolonged sleeplessness, and in some diseases of hearing,—appears chiefly to proceed from the auditory nerve or its corresponding cerebral structures. But at present the details of these phenomena cannot even be investigated so exactly as the subjective visual impressions.

1609. *Smell.*—When certain gases or vapours flow over the mucous membrane of the nose, they give rise to the sensation of smell. A smooth septum (*a*, Fig. 128, p. 232,) separates the two symmetrical divisions of the nasal fossa. The nature of the outer wall is shown by Fig. 322.

FIG. 322.



At *a*, *b*, and *c*, are the projecting turbinate bones, clothed by a mucous membrane which follows their irregularities: at *h* is the hard, and at *i* the soft palate; *f* is the upper part of the pharynx, and *k* the opening of the Eustachian tubes. The network of the olfactory nerve (*o*, Fig. 128, p. 232,) is represented by *p;* and at *q* are some of the sensitive nerves which come from the trigeminal trunk, *v w* (and *s*, Fig. 128). Hitherto the branches of the olfactory nerves—the fibres of which are distinguished by their clear grey colour, their small size, their softness, and their apparent want of medullary matter—have only been followed into the upper and middle part of the mucous membrane of the nose. Their exact mode of termination is unknown: and we are equally unacquainted with the way in which they bring about the olfactory sensation.

1610. Daily experience teaches that very small quantities of many odorous substances suffice to excite the sense of smell. The smell of tobacco, musk, ambergris, or phosphuretted hydrogen, remains attached to paper for years. By partially evaporating a grain of musk on a

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hot plate, we may communicate to a whole room a smell of musk that lasts for many months.

1611. If one volume of an odorous matter be mixed with 100 of air, and one volume of the mixture again diluted with 100 of atmosphere, and this again treated in the same way, — we shall finally obtain a gaseous substance containing only a certain known minimum of the particular odorous matter. Fluid solutions of odorous substances may also be diluted in the same way. This therefore affords a means of approximatively determining the limits to the perceptions of the organ of smell.

1612. A space of air containing $\frac{1}{3000000}$th part of bromine vapour instantly affords an unpleasant smell. Hence it probably requires less than ·00002574 grains of bromine to evoke the peculiar olfactory sensation. A volume of phosphuretted hydrogen gas amounting to not more than $\frac{1}{550000}$th of the whole gives a distinctly garlic odour. The minimum of sulphuretted hydrogen appears to be less than one or two millionths; so that the organ of smell here constitutes the most delicate of all reagents. While on the other hand, a glass rod moistened with hydrochloric acid forms a white fog that betrays the presence of ammoniacal vapour, even when its quantity is too minute to be perceived by the human olfactory sense.

1613. The essential oils (which are often adulterated with fatty oils) are very effective in this respect. It is probable that $\frac{1}{1300000}$th of a grain of otto of roses suffices to give rise to its peculiar smell. After dropping $\frac{1}{13}$th of a grain of oil of cloves into a balloon which contained from 3350 to 3400 cubic inches, its smell remained more than three months.

1614. But of all these substances, the most remarkable is musk. On diluting its alcoholic extract with water, it is found that as little as about $\frac{1}{13000000}$th of a grain can be traced by its smell.

1615. It is important to distinguish between those matters which are really odorous, and those which act upon the mucous membrane of the nose in another way. Twigs of the trifacial cerebral nerve (*s*, Fig. 128, p. 232,) are distributed with those of the olfactory (*o*) in the lining membrane of the nasal fossa. The former give rise to sensations which differ from those of the other organs of touch only in their mode, and not in their nature. While in ordinary language, many of these essentially tactile perceptions are called olfactory. For example, the perceptions produced by caustic ammonia depend chiefly on its corrosive effects. And this probably explains its comparatively large minimum in the odorous scale (§ 1612).

1616. Just as the construction of an organ of voice (§ 1408) only required the larynx to be interposed at a suitable part of the respiratory organ, so something similar obtains with the organ of smell. The current of air which the machinery of respiration drives through the

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nasal fossa only demands the addition of the mucous membrane of the nose, and the twigs of olfactory nerve that supply it.

1617. The nasal fossa is continuous with several supplementary cavities;—such as the antrum of the superior maxillary bone, the frontal sinus, and the ethmoidal cells. But at present the uses of these peculiar structures are unknown. Still, as no fibres of the olfactory nerve can be found in them, we have anatomical grounds for presuming that they do not effect olfactory impressions. Physiological research seems to corroborate this inference. Where disease has afforded free access to one of the maxillary or frontal sinuses, odorous fluids or gases introduced into these cavities have not been perceived to be such. But this fact cannot be regarded as a valid proof; since these experiments imply the absence of many collateral circumstances, which will shortly be mentioned as included in the mechanism of smell.

1618. It is probable that the ciliary movement on the surface of the mucous membrane of the nose (§ 1196) takes an important share in the sense of smell, by producing small whirling currents in the air, and in the odorous particles which this contains. The irregularities of the lining membrane of the nose assist to maintain these various currents. In violent catarrh the sense of smell is always more or less impaired. This fact appears to indicate, that the conditions necessary to smell are capable of being suppressed by the loss of cylindrical epithelium, together with the swelling and the altered secretion of the mucous membrane.

1619. If a tube traversed by odorous substances be introduced as high as possible into the nasal fossa, we shall find that the smell gradually diminishes, and is finally lost. Hence it is not enough that the odorous substances should pass over the mucous membrane of the nose generally. It would rather seem that, in order to give rise to the olfactory sensation, they must traverse a large portion of the entire path prescribed to them. The inferior turbinated bone (*c*, Fig. 322, p. 484) must have a peculiar effect in bending the inspiratory stream. But since we can also smell at the instant of expiration, it follows that this bend is not essential to the olfactory sense. Odorous substances which enter by the posterior nares (*f*, Fig. 128, p. 232) are always distinctly, though feebly, appreciated.

1620. Repeated respiratory movements greatly assist the olfactory sensation. The act of snuffing depends upon an impulsive, strong, and accelerated inspiration. The dilatation of the nostrils must at the same time allow the entry of larger quantities of air.

1621. Weber has pointed out that when a person is extended horizontally, with his head hanging back, we may pour in fluid at one nostril until it runs out at the other. An examination of the throat shows that, under these circumstances, the entrance into the pharynx is nearly

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or quite closed by the soft palate and the palatine arches. This simple fact explains the above experiment. When the fluid contains odorous matters, they are not perceived to be such. Or if these mixtures be injected directly up the nose, we shall get a similar, although less marked, result. Hence we see that when the mucous membrane of the nose is covered with liquid, it loses its capacity of smell. And this inactivity even remains for a few minutes after the fluid has been allowed to run off: so that substances which, like ammonia, operate as caustics, are at first perceived either indistinctly, or not at all.

1622. The delicacy of the sense of smell varies greatly in different persons. While many fail to perceive the most penetrating odours, others can instantly remark their faintest traces. Every person diffuses a peculiar odour, which depends upon the cutaneous exhalation (§ 848). This is so slight, that few notice it. But many savages can thus recognize the path which another person has taken. The instantaneous contact with the ground or with neighbouring substances gives off olfactory substances in quantities which, though minute, are still enough for perception. Dogs and other animals which hunt by scent exhibit a similar perfection of the olfactory organs: their sense of smell conducting them more easily and accurately than that of sight or hearing. And the female animal is frequently provided with special glands, the odorous secretion of which attracts the male from a distance during the rutting season.

1623. Many substances which give an agreeable smell to most persons, seem quite inodorous to others. Mignonette and other plants of delicate perfume are instances of this. And it is even more frequent to find substances, the smell of which is unpleasant to some persons, but attractive to others. The smell of asafœtida is liked by many persons: and hysterical women are often fond of the odour of burnt feathers or other empyreumatic substances. And, conversely, the olfactory organs may be blunted by custom. Workmen who are engaged with putrefying substances, apothecaries, surgeons, and anatomists, exemplify the truth of this last proposition.

1624. A strong smell suppresses the more delicate odours present. If a drop of oil of cloves, and a drop of oil of peppermint, be let fall into a large bottle, the latter will rarely be perceptible. Here also the senses are completely blunted by a want of variety. A person who continually surrounds himself with perfumes becomes at last quite indifferent to them. The most agreeable odours may become repulsive when in excess.

1625. The smell of the odorous body often seems to survive its presence. But although we are justified in expecting that there will be a certain after-impression in the organ of smell as well as in the other senses, still this phenomenon scarcely proves such an effect; since

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it is possible that minute quantities of the odorous substance remain in the nasal fossæ.

1626. Powerful odours often produce stupefaction and fainting. Many cause nausea and vomiting. These energetic effects are probably explained by the intimate connection of the olfactory nerves with the brain. The voluptuous sensations which are frequently felt seem to be only mediate results, effected by the help of memory and imagination.

1627. The attitude which we have to assume in order to perceive any odorous substance constitutes our only means of ascertaining the direction from which it approaches. All those delicate differential phenomena which we have met with in the eye (§ 1523),—and to some extent in the ear (§ 1605),—are absent.

1628. If one of two faintly odorous substances be held before each nostril, the olfactory impression of either may be made to predominate at will. This phenomenon to some extent resembles the contention between the two visual fields (§ 1556).

1629. Subjective olfactory sensations are on the whole very frequent. The mechanical agitation which accompanies violent sneezing may suffice to produce a peculiar smell. But galvanism does not give rise (§ 1578) to any definite impression. It is true that Dupuytren found that dogs into whose blood he had injected odorous liquids began to snuff. But since the odorous matters might have been given off in their own exhalations, we are not justified in regarding this phenomenon as a mere subjective impression.

1630. *Taste.*—We have seen (§ 1621) that the organs of smell are only sensible to elastic fluids. On the other hand, the liquid state is the necessary condition of taste. Insoluble substances at most only cause tactile sensations, such as the feeling of cold: they are unable to produce true gustative impressions. Here again ordinary language fails accurately to distinguish between those perceptions which are proper to the organs of touch, and those which correspond to the true organs of taste. There are many substances to which we are in the habit of ascribing a hot, cold, acid, or caustic taste, although they chiefly excite the sensitive, and not the proper gustatory nerves.

1631. The tongue is usually regarded as the exclusive organ of taste. But an easy experiment may convince us that some parts of this organ are incapable of producing gustative impressions. When a small piece of salt, or a drop of vinegar, or solution of extract of aloes, is placed upon the upper and anterior half of the extended tongue, the peculiar taste of each of these substances fails to appear so long as they do not pass towards its inferior surface or root. While, in the latter situation, the smallest quantity of any sapid substance is distinctly perceived. This is due to the fact, that the nerves of taste are distributed in the

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root of the tongue, while its anterior half is chiefly supplied by nerves of touch.

1632. The upper surface of the tongue is clothed by projections of various kinds, which are called its papillæ. The circumvallate papillæ *l* (Fig. 323) belong to its posterior part. The conical, *i*, and the filiform, *k*,—between which there are often transitional forms,—are found in the

FIG. 323.

other parts of the organ. All of these contain a rich network of capillaries, together with nerve-fibres which effect their gustative or tactile sensations. From what has been already stated (§ 1631), it follows that the circumvallate papillæ occupy that region which offers the most distinct gustative impressions.

1633. It has always been a matter of much discussion whether sensations of taste can only be excited by the tongue, or by other parts of the commencement of the alimentary canal also. However simple the experiments decisive of this question might appear to be, many of them are frustrated by two circumstances, which ought to be constantly borne in mind. When a fluid solution is applied to any part of the palate, it easily spreads into the neighbourhood. Hence we sometimes get gustative impressions, which are wrongly ascribed to the point of con-

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tact. While a soluble and quiescent solid produces either no sensation of taste, or a very slight one. Movement appears to be quite as essential to taste, as the current form of odorous matter is to smell. Hence the substance used as the test ought to be not merely dotted on the part with a pencil, but rubbed here and there; without, however, being allowed to distribute itself over other and more ambiguous regions. Under these circumstances, it sometimes happens that the tactile impression occurs first, while the true gustative sensation only appears afterwards.

1634. Bearing this in mind, it would follow that sweet and bitter substances can be tasted at other places besides the root of the tongue. We meet, however, with individual varieties; which may depend upon the strength of the gustative sensibility, if not upon other peculiarities.

1635. The lips, the inner surface of the cheeks, the gums, the skin of the hard palate, and the greater part of the upper surface of the anterior half of the tongue,—are always devoid of the sense of taste. The quickest and most energetic perception belongs to that part of the tongue which lies immediately in front of the foramen cæcum (*l*, Fig. 323). The under surface of the tongue possesses, in most persons, a vigorous capacity of taste. Positive results are also usually obtained with certain portions of the palatine arch; as well as with the folds which connect the tongue to the epiglottis, the tonsils, the part of the pharyngeal mucous membrane which is opposite to the root of the tongue, and, more rarely, with the soft palate and uvula.

1636. Hence the root of the tongue occupies the first gustative rank; while other parts—and especially the fauces—are also capable of a less delicate and rapid taste. So that the mechanism of deglutition (§ 372) not only affords that movement of the soluble or dissolved substances which is necessary to their being tasted, but forces the alimentary bolus through a narrow path of transit, which also possesses a gustative capacity in numerous situations.

1637. In treating of the nervous system, we shall find that some physiologists regard the glossopharyngeal nerve (*e*, Fig. 323; and *w*, Fig. 128, p. 232) as the nervous trunk upon which the sensation of taste exclusively depends: while others ascribe this capacity to both it and the trigeminal nerve (*g*, Fig. 323; *s*, Fig. 128). We need not now consider the various arguments which support the first of these views. Thus much at any rate is certain, that the root of the tongue, which exhibits the liveliest gustative sensibility, receives a large number of fibres from the glosso-pharyngeal nerve.

1638. We may often notice that there is a tendency to set down all indistinct perceptions of taste as faintly acid, bitter, or saline. This fact gives rise to numerous deceptions: and is very liable to betray us into error in examining the various regions of taste. It is to this cause that

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we may perhaps attribute the opinion, defended by so many experimenters,—that substances such as sulphuric acid, salt, or ox-gall, produce dissimilar gustative impressions, according as they are applied to various papillæ or regions of the organs of taste.

1639. The repeated dilution of a dissolved sapid body finally gives us a mixture which produces no distinct gustative impression. Hence this process affords a means of accurately determining the delicacy of taste, as well as of smell (§ 1611). The taste of sweet substances, such as sugar or syrup, is the first to disappear: the limit being for cane sugar about 1 to $1\frac{1}{2}$ per cent. Salt somewhat goes further. While very acid or bitter substances, such as sulphuric acid, extract of aloes, or sulphate of quinine, are easily recognized in the greatest state of dilution. The taste peculiar to each can be perceived with $\frac{1}{3000}$th to $\frac{1}{5000}$th of a grain of sulphuric acid, $\frac{1}{5000}$th of extract of aloes, and $\frac{1}{2000}$th of basic sulphate of quinine.

1640. We might expect that these results would be determined, not merely by the dilution of the fluid, but also by its absolute quantity. But we find that there is a very peculiar law in this respect. The gustative sensation can be excited by swallowing so small a quantity of a dense solution, that the absolute amount of sapid matter which it contains may be less than that required in a more dilute solution. Hence the greatest dilutions afford no information as to the absolute minimum of a sapid substance.

1641. The varying sensitiveness met with in the organ of smell (§ 1623) recurs in that of taste. While some persons, who are in the habit of tasting wine and tea, can educate this sense to an almost incredible delicacy, others evince a remarkable indifference to gustative impressions. And the putrefying substances which are liked by one man are rejected by another. Custom and prejudice exercise a great influence in this respect. Bitter substances often leave their taste behind them for some time, on account of very small quantities being sufficient for perception. Many substances have an after-taste, which differs from the original one. And if two different sapid substances occupy opposite lateral halves of the root of the tongue, one of them can often be perceived in preference to the other.

1642. It frequently happens that a sapid substance which gives off odorous matters at the same time excites the olfactory organs. But the two senses do not really react upon each other. Nor does their distinctness depend on the mere fact, that elastic fluids are perceived by the nose, and liquids by the organ of taste. Their corresponding sensations rather require the addition of some unknown properties; which, by throwing the nerves of smell and taste into their states of activity, conditionate their several perceptions.

1643. Like the other senses, the organs of taste are probably

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capable of subjective sensations. But in most of the phenomena included under this head it is very doubtful whether an objective impression is not really present. Thus, when a sick person suffers from a bitter taste, it may be questioned whether the altered blood does not give out some bitter substance, which passes through the nutritional fluid, and thus reaches the nerves of taste. The same remark applies to those experiments in which sapid substances have been injected into the blood. And the apparently subjective gustative sensation produced by the galvanic current is perhaps due to electrolytic decomposition.

1644. *Touch.* We shall hereafter see that injuries of the nerves of smell, sight, or hearing, are not followed by any feelings of pain. While on the other hand, those nerves which are the agents of the sensations of touch may, under altered circumstances, give rise to pain. Hence the tactile impressions are said to be effected by *sensitive*, and the operations of the higher senses, by *sensuous*, nerves.

1645. Every free external or internal surface would be of itself adapted to touch, were it not for a peculiar nervous arrangement, which limits the number of sensitive structures. We shall hereafter find that, under ordinary circumstances, few of the intestinal nerves can excite any conscious impressions. While under abnormal conditions, they allow of pain. This explains why we are unconscious of the presence of the food and its residue in the greater part of the alimentary canal; and of the movement of the blood in the heart and great vessels:—why, in short, the greater part of the vegetative functions are executed without consciousness or volition.

1646. Among the parts more or less capable of distinct tactile sensations, we may enumerate the whole surface of the skin; the external auditory meatus; the conjunctiva; the greater part of the cavities of the nose, mouth, and pharynx; part of the œsophagus; the end of the rectum; the urethra; and the lower part of the male and female organs of generation. But we must not regard all of these structures as equally endowed in this respect. The apex of the tongue, and the skin, are the most perfectly so. The remaining surfaces give rise to perceptions which are less distinct, and which easily merge into feelings of pain. Their tactile capacity is, as it were, only a collateral result of their being provided with sensitive nerves (§ 1644). They do not form tactile organs in the strictest sense of the word; this implying a higher grade of the tactile function.

1647. The organs of touch enable us to perceive actions of two kinds. They indicate alterations of mechanical state, and changes of temperature. But in order that the sensation should remain pure, the excitement must not exceed certain limits. Violent impressions of either kind at once give rise to pain.

1648. Beginning by a glance at the preparatory structures which are

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found in the external integument, we see that the latter sustains an epidermis of variable thickness (Tab. IV. Fig. 62, *a*, *b*.). The tactile papillæ of the corium (*d*, *e*,) form prominences, which are more or less closely followed by the layers of epidermis; and which are best seen by the naked eye on the volar or thumb side of the terminal phalanges of the fingers, where they are very large and regular. The nerves which run in the corium effect the tactile sensations, through the intervention of the tissues of the corium and epidermis, on which the result of the impression essentially depends.

1649. Something similar to this is repeated in the other tactile surfaces. For instance, the tongue sustains a pavement epithelium, in place of an epidermis. And its nerves run in a fibrous tissue which lies beneath this layer, and corresponds to the corium.

1650. The simplest tactile sensations are caused by the mechanical resistance which a body offers to the sensitive skin, in virtue of its own consistence, and the compression and displacement of the several cutaneous structures. It is thus we are enabled to judge of the hardness or softness of any substance with which we come into contact. But since the thickness of the epidermis always varies in different parts of the body, the same substance will excite different impressions according to the locality it touches. The same degree of pressure which produces pain at the lips, will only cause a tactile sensation when exerted on the thick epidermis (Tab. IV. Fig. 62, *a*, *b*) of the sole of the foot. While any place that has been deprived of its epidermis, which normally moderates irritation, is pained by the slightest causes.

1651. If two points touch an unmoved cutaneous surface, they can only be perceived separately when the distance between them exceeds a certain limit. And Weber has shown that the minimum of distance thus established varies in different parts of the skin. This experiment enables us to construct a scale of the sensibility possessed by the several tactile surfaces. For this purpose we make use of a pair of compasses, the points of which are armed with suitable pieces of cork; finding out the smallest distance at which they are recognized as separate. A smaller distance than this gives rise to an indistinct impression of a long-drawn point: and finally, on approximating them still more closely, the perception becomes completely single.

1652. The absolute values thus obtained vary greatly from each other. A certain portion of skin may give four or five times as much in one person as in another. The most striking differences are generally found in those parts which themselves offer the highest absolute values. A delicate skin, and an active mind, seem to admit of smaller distances.

1653. The point of the tongue has a more delicate sense of touch than any other part of the body. Here the minimum distance is ·0433 inch. The skin of the middle of the back gives a minimum distance

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of 2·13 to 2·68 inches, and is the region where touch is dullest. Hence the extremes may differ from fifty to sixty-fold.

1654. Assuming that the average for the tongue is =1, the distance for the terminal phalanx of the index finger is 1·2, and for that of each of the remaining fingers 1·8. At the thumb side of the first and second phalanges, it is 3·3; and on the dorsal surface of the last phalanx, 4·4.

1655. The red part of the lips gives 3·1, and the white 4·6. This difference is chiefly due to the unequal thickness of their coverings, and perhaps to their nervous relations. The remainder of the face has a still duller sense of touch. On the outer surface of the eyelids, it is 7·9; on the skin of the cheeks, 9·4 to 10·9; and in the inferior frontal region, 12·4.

1656. The tactile sensibility of the foot is in every respect inferior to that of the hand. For example, the volar side of the terminal phalanx of the thumb gives 1·5; and that of the great toe, 6·7. The dorsal surface of the hand gives from 4·4 to 14·4; and that of the foot, 12·2 to 25·9.

1657. The extremities of the limbs, such as the hand and foot, have a more delicate sense of touch than their middle segments, such as the forearm and leg: while these again are more sensible than the segments connected with the trunk, such as the thigh and upper arm. The two latter belong to those parts which do not possess a high development of tactile capacity. The vicinity of the elbow and the knee-joint is more sensitive, being easily excited to pain.

1658. The face has a more accurate sense of touch than the crown of the head or the neck. The dorsal surface of the trunk is inferior to the abdominal in this respect.

1659. It would seem that, in the adult, these minimum distances alter very little by lapse of time. At least the author finds that his skin gives about the same numbers as it did eleven years ago.

1660. The friction of some parts of the skin gives rise to peculiar feelings of tickling, or to voluptuous sensations. But such parts do not necessarily rank high in the scale of tactile sensibility. Thus the axilla gives 26·9, and the foreskin 10·6, as the minimum of distance.

1661. The tactile sensibility is capable of being increased by habit to an extraordinary degree. In this way some blind persons are able to recognize different colours by inappreciable differences in their grain. The Bengalese spinning women can distinguish the threads of the cocoon with a tactile delicacy which is almost incredible. And persons devoid of arms may educate the sensibility of the toes, until it corresponds with that of the fingers of an ordinary individual.

1662. In judging of the delicacy of touch, we usually take the minimum distance at which two points can be recognized as the unit from which to start. This fact explains a peculiar illusion, to which attention was first drawn by Weber. When we draw the protected points of the compasses downwards from the cheek to the lips, it seems as if the distance

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between them gradually increased, in consequence of our thus proceeding from a less sensible part to one which is more so.

1663. At present we are unable to assign the exact causes of the degrees of tactile sensibility possessed by different parts of the skin. Here and there a varying thickness of epidermis may assist to increase or diminish the delicacy of touch. But this difference is not always parallel with that of the tactile capacity. Many physiologists have supposed that a part which has a smaller minimum distance possesses more nerves. But hitherto this supposition has not been proved:—on the contrary, it may be definitely denied that the nerves of the skin of the back are 50 to 60 times less numerous than those of the apex of the tongue.

1664. The perceptions of touch appear to occur somewhat more slowly than those of the other senses. Here also, a stronger stimulus easily suppresses a weaker one. The addition of painful sensations readily destroys the tactile impression.

1665. When the eyes are bandaged, the place upon which pressure is being made by any substance is stated with more uncertainty, the less acute the feeling of the corresponding part. For the same reason we often blunder in attempting to lay hold of a definite point of the neck, the back, or the leg. When various neighbouring portions of skin are pressed at the same time, our judgment is greatly facilitated by the unequal excitement of the several parts. And it may be rendered still more exact by simultaneous muscular contractions or displacements.

1666. The sensibility of the various parts of the skin greatly influences our judgment of the peculiar forms possessed by the objects we touch. The perception which is produced by the pressure of a hollow tube or prism only becomes a distinct one, when the diameter of the apposed body exceeds the minimum distance of tactile sensibility. In like manner, a very sensitive part of the skin recognizes small roughnesses more accurately than one which is less so. On rubbing a woven hair-chain against the skin of the neck, we get an impression which is much less definite than when the experiment is repeated at the point of the tongue.

1667. The clearness of our perceptions is greatly increased when the tactile surface of the skin is made to glide over the body which is being examined. Our consciousness of the way in which the contractile tissues have to act in order to bring about the result, frequently affords a decision which must have otherwise been suspended. It is only with this assistance that the blind are able to recognize the forms of many bodies.

1668. The pressure which a quiescent body exerts on a tactile surface affords tolerable information as to its weight. Here again, if the muscles have to contract to a certain degree in order to afford the necessary resistance, the delicacy of the perception will be greatly increased: since our consciousness of the amount of contraction requisite for this purpose

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facilitates a comparison. We may best convince ourselves of this fact by estimating a weight with the supported and unsupported hand successively.

1669. For example, Weber[44] found that, in the first case, weights could be distinguished which were to each other as 29 to 30. While, when wrapped up in a cloth, and suspended free, they were distinguishable with proportions of 39 to 40. The author found that he could estimate weights about twice as delicately when he held them free in the hand, and executed the necessary movements.

1670. When a billiard-ball is allowed to roll down the cheek towards the lips, it appears to increase in weight: a deception which, though less marked, resembles that of the distances formerly mentioned (§ 1662). And in general, the more susceptible parts of the skin appear to recognize smaller differences in the weights with which they have been gradually laden. Still we often find that parts (such as the hand and fore-arm) which differ greatly in their perception of distances, exhibit but very slight differences in this respect. Thinner portions of skin enjoy more advantage in this respect than in the determination of distances.

1671. The right hand appears to appreciate pressure better than the left. A mass which is very bulky, or which possesses a temperature very different from that of the skin, is liable to be estimated by most people as heavier than it really is.

1672. When two nearly equal weights, of equal surface and temperature, are placed upon the same part of the skin immediately after each other, the estimate is generally more correct, the shorter the interval of their application. Here, as in the other senses, the recollection gradually diminishes in delicacy.

1673. Although the tactile surfaces are capable of affording information as to temperature, still they cannot do this like a thermometer. For they give no impressions of fixed temperatures, but only of those changes which are produced by the equalization of differences in the amount of heat. A body in contact with the skin only appears to be warm or cold, in so far as it alters the temperature of the tactile surface itself.

1674. Although little is known of the mechanism of our sensations of temperature, still there are two points on which we may theorize with great probability. Since the volume of solids and fluids is altered —although in a very slight degree (§ 182)—by changes of temperature, the molecules of the tactile organs will thus be displaced. This displacement perhaps re-acts upon the nerves of sensation which they enclose. But since it is chiefly the variations of temperature which we recognize, the impression that causes the perception must be transient and fluctuating. This would offer a certain resemblance to the effects of that equalizing electrical curve (§ 232) which obtains on making and breaking the circuit, and leads to contractions chiefly at those times (§ 1241).

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1675. The degree of heat already possessed by the skin forms the measure by which we generally estimate the temperature of other bodies. If we dip the hand in water at 104°, a fluid at 89·6° will at first appear cold. But if the organ of touch have been in a liquid at 68°, the same fluid will seem to be lukewarm.

1676. The conducting power and specific heat of the bodies in contact with our tactile surfaces will obviously exercise a great influence on the impressions of temperature which we receive. Hence, when a series of rods of the same form and bulk, but of different metals, occupy the same water-bath, the copper produces a very different impression to the lead. The feeling of cold caused by quicksilver may be explained in similar way.

1677. When a hot body touches the surface of the skin, its tissues become dry. This circumstance alone is capable of producing pain. The unpleasant impression therefore ceases, or at any rate diminishes, when the burnt portion of skin is held in cold water, until its previous state of tension is restored by transudation. But since fluids also burn, it follows that the equilibrium of the nerves may be permanently disturbed, not merely by this mechanical displacement of the cutaneous tissues, but also by the induction of higher degrees of temperature. And the long subsequent duration of the pain teaches us, that continuous molecular changes here occur.

1678. A person may dip his hand for an instant into a mass of molten metal without injury. This experiment, which is often performed by jugglers, essentially corresponds with that known in physics under the name of Leidenfrost's experiment. If a platinum spoon be made red hot, a drop of water flung into it will take a spheroidal form, and become rounded like a globule of mercury, without undergoing boiling. When the platinum is allowed to cool, there comes a point of time in which the water begins to boil violently. It is probable that, in the first case, the globule of water is surrounded by a layer of vapour, which prevents the necessary elevation of its temperature. In like manner, the epidermis is not only always moist, but is surrounded by other volatile substances. Hence the mass of vapour which it gives off forms a layer that is able to protect us from being burnt during a short space of time.

1679. We may easily convince ourselves that the different parts of the skin are not equally sensitive to the pain of burning. The region of the elbow is much more sensitive in this respect than some others, which can better distinguish the minimum distance of two bodies. The result seems to be chiefly determined by the thinness of the epidermis, and by the amount of nerves which the organs of touch possess.

1680. The locality of the organs of touch also determines the time after which the pain of burning appears. For example, the point of the tongue and the last joint of the index finger can remain 4 seconds, and

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that of the middle finger only 3 seconds, in water at 176°. Heated substances which are placed upon more sensitive parts of the skin appear to us to be hotter. And when a large surface of the skin is dipped into warm or cold water, the fluid appears to be of a higher or lower temperature than if smaller tactile surfaces are used in the experiment.

1681. When the skin is penetrated by great cold, signs of numbness first appear; together with feelings of itching, creeping, formication, or stinging. The tactile sensibility suffers greatly; so that the contact of bodies is much less distinctly felt. We experience an impression, as if some substance were interposed between them and the surface of the skin. It is probable that this feeling is chiefly due to the commencement of coagulation in the nervous medulla. The further effect of the low temperature is shown by a lively feeling of pain, which is not limited to the surface of contact, but shoots along corresponding distributions of the nerves. For instance, when the elbow is plunged into ice, the unpleasant sensation sometimes extends down to the fingers.

1682. It may be stated generally, that pain is only produced by bodies which have a temperature under 50°, or over 122°. Hence burning implies an amount which considerably exceeds that of the ordinary animal heat (§ 1165), and must seriously disturb the molecular condition of the nerves.

1683. The unequal temperature of the skin in different regions, which are subjected to different causes of cooling—together with the different thicknesses of those bad conductors of heat which protect the organs of touch (§ 204)—render it impossible to construct an exact scale of the susceptibility to temperature possessed by its several parts. The former circumstance often deceives us when we attempt to determine the temperature of two fluids at once with both hands. While when mixtures the temperatures of which are nearly alike are examined with the same hand in immediate succession, we often come to a pretty accurate estimate. When no feelings of pain interfere, sensitive persons can distinguish differences of ·45° to ·9°.

1684. Painful feelings of temperature suppress the more delicate tactile sensations. But, under voluptuous excitement, the pain may be unnoticed,—at least at the time. Persons suffering from eruptions are often seen scratching them until they bleed, with strong sensations of pleasure, which are only later replaced by more or less pain. And onanists frequently wound their genitals, in order more fully to satiate their unnatural lust.

1685. Although most of the organs of touch are symmetrical and in pairs, still two corresponding parts of skin never furnish a single impression. Hence we have here no phenomenon which parallels the corresponding portions of the retinæ. We do, however, meet with something analogous to double vision. But the double feeling manifested under

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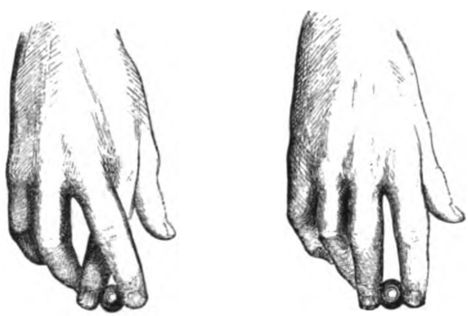
certain artificial arrangements depends upon causes altogether different to those of the double images which are perceived in voluntary squinting, or with an unsuitable adjustment of the conducting lines (§ 1549).

1686. When a ball (*a* Fig. 324) is rolled between the opposed sides of the index *c* and middle finger *b*, we get the ordinary single impression. But when, on the other hand, these two fingers are crossed as shown at *e* and *f*, and *d* is made to glide up and down, we fancy we feel two balls. The cause of this perception lies in the fact, that the evidence of

FIG. 324.



the active tactile surface is referred to our general judgment. The ordinary position *b c* offers two apposed concave surfaces, which our thoughts complete to a single ball. While, on the other hand, *f* gives a concavity which is referred outwards, and *e* one which is referred inwards,—impressions which we therefore seek to complete as two more or less perfect spheres. But when we cross the thumb and little finger, this double feeling is absent; because our judgment is aided by the freer muscular movement of these parts, and by the less constrained position which this enables them to take.

1687. The subjective impressions of the organs of touch may be reduced to (or at least partially explained by) the different modes of action of which they are capable. Hence we have sensations of pressure, prickling, burning, shivering (§ 1176), and the like. Such disturbances often give rise to errors of perception. A person suffering from partial paralysis of the soles of his feet not unfrequently feels, when standing, as if a bladder of water were placed under these organs. When a part of the upper or under lip is completely paralyzed, the patient sometimes fancies that a piece is broken out of the glass from which he is drinking. Here, as in our mental life, we are often inclined to charge upon others the subjective faults which belong to ourselves.

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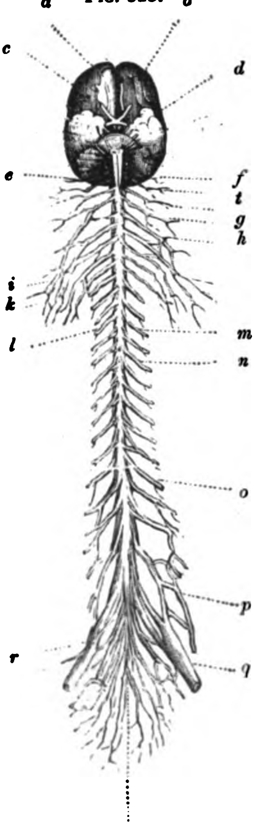
CHAPTER XVIII.

INNERVATION.

1688. The most important advantages enjoyed by the animal are due to the nervous system. For, in the first place, it forms an indispensable link in all those actions which are usually ascribed to the mental powers. Beside this, it conditionates the external sensations; induces the voluntary, and most of the involuntary, contractions; and exerts an indirect influence on all the other functions. And in particular, the contractility possessed by some of the constituents of most organs allows their adjustments to be modified by the nerves. It is on influences of this kind that most of the phenomena of self-regulation (§ 17), which impart such a complex character to the animal apparatus, chiefly or exclusively depend.

FIG. 325.



1689. The nervous system is divisible into two chief portions; a centre, and a periphery. The former appears at first sight to be constructed very differently in the vertebrate and invertebrate animals. But microscopic observation teaches that the difference is not so essential as might be thought from a mere examination with the naked eye.

1690. The annexed woodcut (Fig. 325) is a rude outline of the human nervous centre, and the commencement of its periphery, as seen from before and below. The centre consists of the brain, *a b e f*, and the spinal cord, *s t*. Each of these gives off a series of nerves, which are thence called the cerebro-spinal nerves; or the cerebral and the spinal nerves, according to their different origin. For example, *c* and *d* belong to the former group of nervous cords, and *g h i k l o p r* to the latter; which are subsequently distributed to the several tissues of the body. This contrast between the brain and spinal cord on the

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one hand, and the peripheric nerves on the other, is repeated in all the vertebrata.

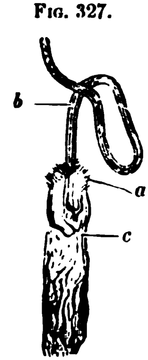
1691. The nervous centre of the invertebrate animals does not consist of a continuous cerebral or spinal mass, but of a series of ganglia, which are united to each other by smaller nervous cords. But the forms which they take are very various. For example, Fig. 326 represents that generally seen in insects and most articulata. The greater part of the ganglionic cord runs near the under surface of the animal, and is therefore usually called the abdominal cord. A nervous ring, the œsophageal, surrounds the commencement of the alimentary canal. The ganglionic mass which lies above this,—and hence in the superior half of the animal,—is frequently designated the cerebral ganglion.

FIG. 326.

1692. *Periphery of the nervous system.* Here an examination with the naked eye first distinguishes two kinds of substance: *viz.*, nerves of a more or less cylindrical form, and ganglia which essentially correspond with the thickenings represented in Fig. 326. The nerves are composed of primitive nerve-fibres (Tab. V. Figs. 68 to 70). While on the other hand, the ganglia contain, in addition to these, peculiar structures called ganglion-globules or corpuscles (Tab. V. Figs. 71 to 74). The latter therefore form another important constituent of the peripheric nervous tissues.

1693. Every nerve-fibre (Tab. V. Fig. 68) consists of a thin membrane or sheath—the neurilemma—which encloses a peculiar oily content, the nervous marrow or medulla. The latter appears to be quite homogeneous during life. But after death, it is very apt to coagulate, especially on the access of water or other injurious fluids (Tab. V. Fig. 69). Sometimes the central part of the medulla separates from that around it; and not unfrequently coagulates in striæ. A peculiar structure is thus produced, which is called the primitive band (*b*, Fig. 327), and which often protrudes from one end of a torn nerve-fibre. In other instances, however, the central part is distinguished by its more homogeneous characters. It has therefore been distinguished from the cortical part of the medulla by the name of the axis cylinder.

FIG. 327.



1694. A microscopic examination of the smaller and more transparent nerves will generally convince us that their several fibres run separately near each other, as shown by the diagram, Fig. 328. When a

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branch *A* divides into two subordinate ones *B* and *C*, the primitive fibres *a b c d e f*, which were formerly united in *A*, separate into two groups. The fibres *a b c d* are retained by *C*, which is continuous with the chief trunk *A;* while *e* and *f* pass into *B*.

Fig. 328.

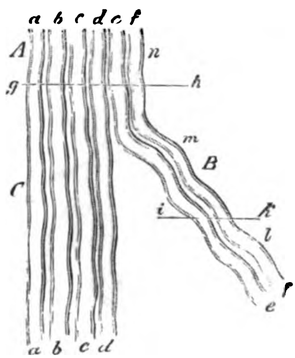
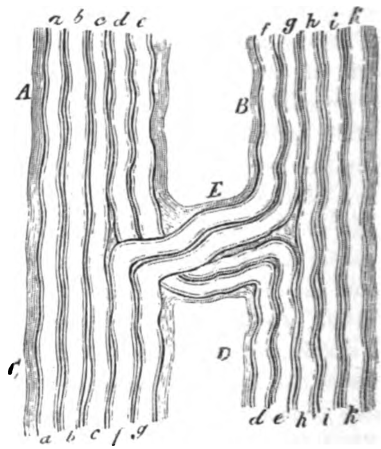


Fig. 329.



1695. The anastomoses which unite many nervous trunks with each other depend upon similar circumstances. For instance, in the union of *A* and *B* (Fig. 329) to each other by the intervening branch *E*, the fibres *f* and *g* pass from *B* to *C*, while *d* and *e* go from *A* to *D*. It is obvious that such arrangements will permit them to take a variety of courses. Other circumstances being equal, if *E* conduct more fibres from *B* to *C*, than from *A* to *D*, *C* will be larger than *A*.

1696. The frequent repetition of such anastomoses, and the reticular union they produce, give rise to the plexuses of the nerves. The spaces between their meshes may be filled either by ganglion-corpuscles, or by less important structures. In the latter case the plexus is called simple, and in the former, compound. In any case there is a manifold interchange of nerve-fibres.

1697. From what has just been stated it is evident, that the branches and unions of the nerves have quite a different signification from those of the vessels. The tubes traversed by the lymph or blood really divide, and often really unite with each other. But in the nerves these appearances are generally deceptive. Their branches and anastomoses are usually due to a mere change in the situation of their minute elements,—*i.e.*, of their primitive fibres, which are only brought into view by the magnifying glass. The law of these structures obliges them to take an isolated or separate course: in short, like the coiled wires of an electric spiral

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(§ 220), they are virtually distinct from each other, and only pass in company.

1698. Until lately this law was supposed to have no exception. But recent researches have led to the conviction, that true divisions do sometimes occur. The commonest example of this kind is given by Tab. V. Fig. 70; where the fibre *a* divides into the subordinate branches *b* and *c*. Divisions into many small branches are less frequent. They have, however, been seen in the membranes endowed with sensation, in the organs of locomotion, in voluntary and involuntary organs, in the larger nervous trunks, and in the terminal distribution of the nerves. They certainly seem to be most frequent just before the nerves reach the end of their peripheric course. Still they are sometimes present in situations prior to this.

1699. Supposing that the above law always held good, and that every fibre was completely isolated throughout its whole course, the number of primitive fibres in the total peripheric system would not exceed that contained in the roots of the cerebral and spinal nerves. But the presence of these divisions augments the number of primitive fibres. Hence it must directly increase the quantity of nervous medulla. It also leads to many other physiological results, to which we shall hereafter return.

1700. Those smaller branches of the nerves which run in the interior of organs generally form plexuses; which can be recognized, either with the naked eye, or under low magnifying powers. They are called the terminal plexuses of the peripheric system. It is obvious that their first effect is to mix the various primitive fibres. But there are physiological reasons for conjecturing that this is not their exclusive object. In many cases we find that a primitive fibre passes into the plexus of another branch, to return, after some time, into its former trunk. From this we might conclude that the presence of the terminal plexus subserves two other purposes. It lengthens the path which the primitive fibres have to traverse before reaching their peripheric termination; and hence increases the quantity of the active nervous medulla. It also enlarges the number of the mutual points of contact, and thus multiplies those collateral actions of the several nerve-fibres which they permit.

1701. Many nerve-fibres seem to lose their distinctly medullary contents before reaching their peripheric termination. This peculiarity,—as well as the division of the medullary fibres,—is better seen in the plates of the electrical organs of the torpedo than in any other structure. The oily content *a f* (Fig. 330) disappears at *b*, beyond which we see only yellowish-grey branches apparently void of medulla. The latter are enclosed in a thick membrane; so that it remains at present undecided what are their contents, and how the transition occurs at *b*. Rudolph Wagner and other observers believe that something similar to this

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is repeated in the muscles, the vascular glands, and many other organs.

1702. The way in which the nerve-fibres end in the various organs of the body has been a subject of much dispute. The opinion, that they become continuous with the several foreign tissues in their neighbourhood, is very properly abandoned by almost all observers. At present the contest lies between two theories. One of these supposes that the nerves have a free termination, and either contain medulla to the last, or undergo a transition into those apparently marrowless fibres just mentioned (§ 1701). The other regards them as ending by curved loops, in which two fibres meet in the form of an arch, as indicated by Fig. 331.

Fig. 330.

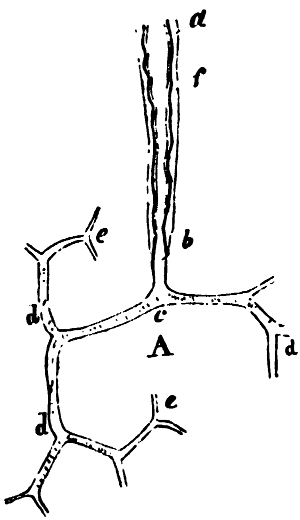


Fig. 331.

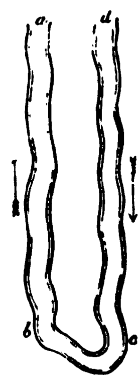
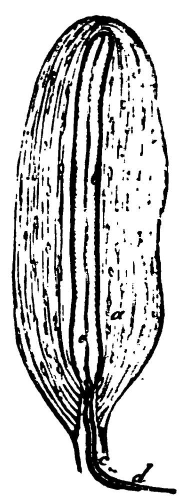


Fig. 332.



1703. The chief difficulty of deciding the question arises from the fact, that there are very few organs in which the nerves can be unmistakeably followed to their termination. The appearances of a free extremity are open to this objection,—that it is always possible, or even probable, that their course has been but imperfectly followed. And against the looped ends it may generally be alleged, that we are perhaps only looking at a simple bend of a nerve-fibre, which subsequently continues onward to its true termination. But since these loops are found in small organs, such as the tooth-sacs, which can be completely and thoroughly inspected,—this objection cannot always be maintained.

1704. In the mammalia, many of the smaller nerves are occupied by peculiar enlargements, which are usually called Pacinian corpuscles. They are most frequently found in the nerves that run in the mesentery of the cat, and in the palm of the human hand, and sole of

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the foot. One of the simplest forms of these bodies is represented by Fig. 332. It consists chiefly of a bulbous and stratified capsule *a*, in the central canal *b* of which runs a primitive fibre *e*. There is often a peduncle *c* at the place of its attachment. The nerve-fibre *d* gradually undergoes an alteration in the character of its medulla. It becomes paler; and on entering the capsule *a* it sometimes divides, and frequently ends by becoming very indistinct. Hence many have supposed that the Pacinian corpuscles plainly enunciate the general law of a free termination of nerve-fibres. But there are several objections to this view. We may sometimes distinctly see that the nerve-fibre only passes through the Pacinian corpuscle. It may also be questioned whether the whole structure is not due to extraordinary collateral circumstances, which can finally break off its connection with the primitive fibre. While the proportionate number of nerve-fibres which enter into Pacinian corpuscles is so small as scarcely to warrant us in deducing any general law.

1705. So far as we know, each particular nerve-fibre has a determinate direction of activity—has, so to speak, a certain one-sided mode of action, a peculiar and special energy. These influences are divisible into three kinds. The fibres of the nerves of special sense respond to the stimuli which meet them by their proper sensuous phenomena,—by seeing, hearing, smelling, or tasting; and those of the sensitive nerves, by sensations of touch or pain. On the other hand, the motor nerve-fibres excite the muscles to contraction.

1706. We shall hereafter see that every local irritation of a nerve results in a certain molecular change of its nervous medulla. Where the stimulus and its after-effects are strong enough, the excitement is probably propagated along the whole course of the primitive fibre. But both in the centre and periphery, the fibre adjoins certain foreign tissues. And hence two modes of action are possible. The stimulus may excite, either certain parts of the centre, or the corresponding peripheric organs. If one of these acts as the cause, the second will appear as the effect. The three groups mentioned in the preceding paragraph differ essentially from each other in this respect.

1707. Let us suppose *a b c* (Fig. 333) to be sensuous, *d e* sensitive, and *f g h* motor, nerve-fibres. The two first classes will conduct their impressions centripetally:—*i.e.*, from the peripheric organ of sense towards the nervous centre; or in the directions *D C A* and *E B*. Thus the rays of light which impinge upon the retina, or the waves of sound which strike the auditory nerve, begin the corresponding action: which ends by its respective impression being perceived at the centre. The action of the motor fibres is precisely the reverse of this. When we voluntarily contract a muscle, the change begins in a certain part of the brain. The excitement of the motor nerves then takes a peripheric

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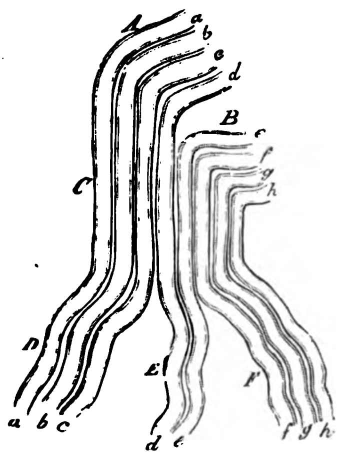
course from *B* towards *F*: and the contraction of the muscles is its final result.

1708. Hence we may regard each of the above nervous actions as consisting originally of three processes. The stimulus excites the peripheric sensuous or sensitive organs; and the central motor organs. And just as the phenomena of induction translate the electric current into magnetism, and *vice versâ* (§ 250), so the first stimulus is converted into a second, which runs along the nerve-fibres. When this has been conducted centrally to the brain, or peripherally to the organs of movement, a second transfer occurs; which is the counterpart of the first, and produces the final result.

Fig. 333.



1709. It is not necessary that the original stimulus should proceed from those tissues which surround the peripheric ends of the centripetal fibres, or the central ends of the centrifugal fibres. On stimulating a motor nerve in the middle of its course, the corresponding muscles contract: or repeating the experiment on a sensuous or sensitive trunk, a sensuous or painful impression is produced.

1710. That molecular change of the nervous medulla upon which the activity of the primitive fibres depends, can only be propagated when the particles retain their natural arrangement and properties. This proposition, which we have already been obliged to lay down for the phenomena of movement (§ 1237), explains why the action of the nervous medulla is paralyzed by section, chemical or electrolytic changes, or serious disturbances of its nutrition. At the same time, it is obvious that the phenomena of the centripetal and centrifugal nerves will be, to some extent, the reverse of each other. If we suppose *e f*, Fig. 328, to be two sensuous or sensitive fibres, having their peripheric ends below,—an injury at *i k* will completely paralyse *l*; while *m*, which retains its connection with the brain, will still be capable of producing subjective sensuous perceptions or pains. And conversely, if *e* and *f* were motor, *l* could produce muscular contractions, while *m* would have no effect. Hence the capacity of excitement is retained by the central segment of the centripetal nerve-fibre; and by the peripheric segment of the centrifugal one.

1711. The site of the injury must also determine the extent of the subsequent paralysis. When the section is at *i k* (Fig. 328) only *e* and *f* are rendered inactive. But when it is above, at *g h*, the disturbance

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extends to *a b c d e f*. It is obvious that the plexuses will give rise to great complications in this respect.

FIG. 334.

1712. That mixture of the several primitive fibres which their mutual anastomoses effect (§ 1695), cannot be satisfactorily followed for any distance, either with the naked eye or the microscope. Hence anatomical research rarely furnishes trustworthy details respecting the course of a single nerve-fibre, or even of the larger bundles and roots of nerves. But physiological experiments sometimes afford more satisfactory results. For instance—setting aside those collateral disturbances which we shall hereafter mention—the stimulation of a particular nerve always leads to the contraction of that corresponding portion of muscle, in which its fibres terminate. Something similar obtains with the tactile impressions of a given part of the cutaneous surface. Knowing the nervous injuries after which the sensibility of any part is lost, we may thence deduce the terminal distribution of its corresponding sensitive nerves.

1713. For instance, Fig. 334 shows the sciatic plexus of a frog, laid bare from behind. It contains four chief trunks: *a* is the inguinal or seventh spinal nerve, *b* is the femoral or eighth, *c* is the sciatic or ninth, and *d* the pubic or tenth. All four subsequently unite in a single trunk; which supplies the corresponding hind leg, and the neighbouring structures.

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1714. On stimulating the inguinal nerve *a* of a newly killed frog, a great part of its femoral muscles contract: together with—in exceptional instances—some muscles of its leg and toes. Stimulation of the femoral nerve *b*, and of the sciatic *c*, is responded to by the muscles of the thigh, leg, and toes. The action of the pubic nerve *d* is often limited to the muscles of the anus and coccyx: but may extend to some of the muscles of the hind leg, and down to the toes.

1715. When these experiments are made on a number of frogs, the details of their results often differ from each other. For although the chief regions affected are tolerably constant, still muscles which obey a particular nerve in one frog, are excited in a second animal by another. In addition to this, the same muscle often appears to be governed by several nerves. Indeed, the quadriceps extensor of the thigh is sometimes excited to contraction by all four trunks of the sciatic plexus.

1716. This peculiar phenomenon may be ascribed to various causes. It often happens that primitive fibres of two or more nerves enter the same muscle. So that here the result corresponds to the fact.* But it is also possible that these appearances are deceptive. Thus we shall hereafter see that the excitement of one fibre may possibly be transferred to another near it, especially in the region of the terminal plexus. In electrical irritation by means of the electro-magnetic (§ 248) or rotary (§ 252) machine, this is very liable to occur. Hence there is reason to doubt all statements which enter too much into details.

1717. The study of the nervous centre will teach us that muscular movements are not only produced by the motor nerves, but—at least mediately—by sensitive fibres. On irritating any part of the skin, the change is propagated along the sensitive fibres to the spinal cord or brain. Here the impulse may be transferred to certain motor fibres. And hence the corresponding muscles may contract as though they were thrown into action by the influence of the will. The contractions produced in this indirect way are called reflex movements. They can only occur where the co-operating sensitive and motor fibres, and the corresponding part of the nervous centre, alike retain their force. But section of the sensitive fibres removes one of these essential conditions. So that we have here another means of determining their terminal

* Every anatomist must have remarked great varieties in the distribution of the small nerves of the arm and leg. Now we cannot doubt that the function of each fibre requires that it should unite some two specific points of centre and periphery. And it is just as obvious, that the co-ordination of several fibres will imply an equally definite relation of each to all the others. It is possible that this is effected by a suitable admixture of fibres in the plexus. But, in any case, these varieties sufficiently prove, that a nerve with a given name need not—and does not—represent a definite collection of really identical fibres. From obvious reasons (§ 1697) the exact composition of any particular branch seems to be neither constant nor essential. Beyond the plexus, at least, its several fibres may vary their routes without any alteration of their functions. And the frequency of such deviations would quite account for the diverse results obtained by stimulating what is to all appearance the same nerve in two different animals.—EDITOR.

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distribution in an animal which is newly killed, and still inclined to these movements. For instance, we have but to divide the various trunks of the sciatic plexus, or their sensitive roots (§ 1720), and examine what parts of the skin have lost their excitability to reflex movement. In this way Eckhard[45]) found that the sensitive fibres of the seventh spinal nerve (*a*, Fig. 334) were distributed chiefly to the thigh, and those of the eighth (*b*) to certain parts of the skin of the whole hind leg, those of the ninth (*c*) to the leg and foot, and those of the tenth (*d*) to the neighbourhood of the anus. The sensitive and motor fibres included in one nerve, do not always run to the skin and muscles of the same part of the body.

1718. The action of the various parts of the peripheric nervous system is one of the chief problems of that part of the science of life with which we are now occupied. We have to determine what functions belong to the roots and trunks of the different nerves, and whether they are pure or mixed: *i.e.*, whether they contain only one kind of fibres——sensuous, sensitive, or motor—or two or more of these together. Mere anatomical examination can decide nothing in this respect:—since sensitive fibres frequently pass through the muscles; while the organs of touch often enclose contractile tissues, to which motor fibres are probably given off (§ 1235). Hence such decisions require the aid of physiological experiments.

1719. The spinal cord of the human subject (*s t*, Fig. 325, p. 500) gives off a double series of nervous cords, which are called the roots of the spinal nerves. The annexed woodcut (Fig. 335) represents a piece of the spinal cord, *a a*, of natural size. Its external membrane or dura mater, which is slit up and opened out posteriorly, is indicated by *b*. At *c* is the denticulate ligament, which is covered by a fold of the arachnoid or middle membrane of the spinal cord. Finally, the pia mater or innermost sheath lies immediately on the medullary substance of the spinal marrow itself. On the left side are seen the uninjured posterior roots of the spinal cord. On the right they have been cut through; the central part *d* being still attached to the spinal cord, while the peripheric portion *e* is severed from it. These roots subsequently enlarge into the posterior spinal ganglia *h*. Each anterior root *f* finally unites with a posterior to form the trunk of a spinal nerve. Immediately after leaving the intervertebral foramen, this divides into an anterior and a posterior branch, *i i*, which are destined to supply the corresponding parts of the body. These trunks next ramify with numerous anastomoses, and finally terminate in the various organs of the trunk and limbs.

1720. It is to Sir Charles Bell that we owe the discovery that,—as regards the tactile surfaces of the skin, and the voluntary muscles of the trunk and limbs,—the posterior roots of all the spinal nerves are

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purely sensitive, and those of the anterior purely motor.* We may easily convince ourselves of this in the frog. On laying bare the nervous

FIG. 335.

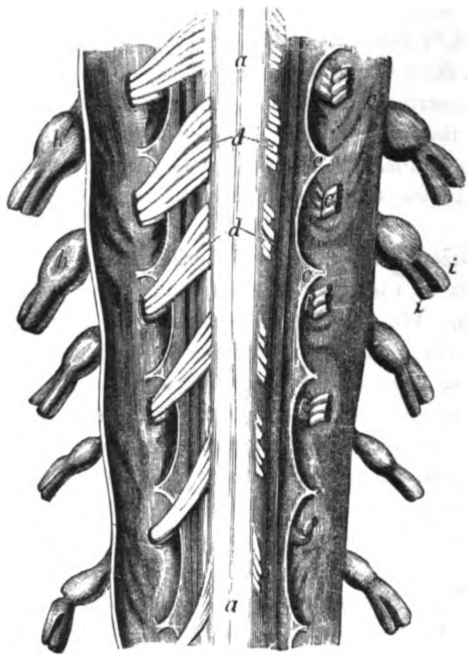
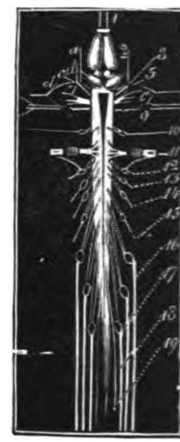


FIG. 336.



centre of this animal from behind, and cutting through, on one side, the posterior roots of the four last spinal nerves (16, 17, 18, 19, Fig. 336), which enter into the sciatic plexus (§ 1713), and supply the corresponding hind leg, the limb loses all sensibility to touch or pain. The foot may be burnt to a coal, without any sign of suffering from the animal. In spite of this, however, he moves the stump at will. And conversely, when the anterior roots are divided on the other side of the same animal, the will has no longer any influence on the limb; while tactile impressions are plainly perceived by its skin. The law thus discovered by Bell plainly shows, that the various primitive fibres of the spinal cord emerge with a symmetrical arrangement. The posterior are aggregations of sensitive structures, without any which can subserve to muscular motion. The anterior exactly reverse this proposition.

* The complete accuracy of this statement is somewhat affected by an important experiment, which we owe to M. Magendie, and which establishes what he calls the "recurrent sensibility" of the anterior roots. In other words, the motor root is also sensitive to pain. And this property is derived from the corresponding sensitive trunk. For after section of the anterior root, the central of the two cut surfaces is insensible, while the peripheral is sensitive. And finally, cutting across the posterior root deprives the peripheral surface of all sensibility. In 1850, the kindness of M. Claude Bernard enabled me to verify the details of this discovery on a dog, which he subjected to the above experiments with his usual admirable skill.—EDITOR.

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1721. The trunks which arise from the fusion of the two roots are obviously mixed nerves, as are also their subsequent branches. It is doubtful whether there is any further separation of the sensitive and motor fibres in the terminal plexus (§ 1718).

1722. Those parts of the nervous centre which are enclosed in the cavity of the skull, give off several pairs of nervous trunks, which are usually designated the cerebral nerves. The greater part of these, however, do not proceed from the brain itself, but from its connection with the spinal cord, and brain, or from the medulla oblongata. Strictly speaking, the brain only gives off the olfactory (§ 1609), and part of the optic, nerves. The common nerve of the muscles of the eye proceeds from the crura cerebri, and the remaining cerebral nerves come immediately from the pons varolii and the medulla oblongata.

1723. The cerebral nerves of the right side are shown, as they leave the cavity of the skull, in Fig. 337. The brain itself has been removed in order to allow a better view of the nerves within the skull.

The 1st is the olfactory nerve *o;* the 2nd, the optic *p;* the 3rd, the motor oculi, *q;* the 4th, the nervus trochlearis seu patheticus, *r;* the 5th, the trigeminate nerve, *s;* the 6th, the nervus abducens, or nerve to the external rectus, *t;* the 7th, the facial nerve, *u*, and the auditory nerve, *v;* the 8th, the glosso-pharyngeal, *w*, the vagus or pneumo-gastric, *x*, and the spinal accessory, *y;* and, finally, the 9th, the hypoglossal nerve, *z*.*

1724. The olfactory nerve (*o*, Fig. 337), the branches of which are distributed in the mucous membrane of the nose (*p*, Fig. 322, p. 484), is the medium of the impressions of smell. Stimulating it gives rise to subjective olfactory phenomena (§ 1629). But no pain or direct muscular contractions result.

1725. In like manner, the optic nerve (*p*, Fig. 337), the fibres of which are distributed over the retina, gives rise to visual impressions which are unaccompanied by any direct sensitive or motor reactions. The reason why both optic nerves are united in the chiasma (Fig. 259, p. 429) has not yet been discovered.

1726. The third nerve (*q*, Fig. 337) contains a large number of motor fibres, which are distributed to most of the muscles of the orbit, to the iris (*b*, Fig. 150, p. 273), and probably to other structures in the interior of the eye. It governs the levator palpebræ superioris (*g*, Fig. 260, p. 430),

* Here the enumeration of the cerebral nerves used in this country has been substituted for that given in the original. In the latter, the facial and auditory nerves form the 7th and 8th: while the glossopharyngeal, pneumogastric, and spinal accessory are the 9th, 10th and 11th; and the hypoglossal completes the series of 12. Both these sets of numbers are so far objectionable that they represent as a nerve the lobe of the nervous centre from which the proper olfactory nerves arise. But that generally adopted by British authors has the graver disadvantage of confounding in its seventh number a motor (the facial), a sensuous (the auditory), and probably also a sensitive (the *portio intermedia*) nerve. A similar objection might be made to the union of three equally diverse elements in the eighth nerve.—EDITOR.

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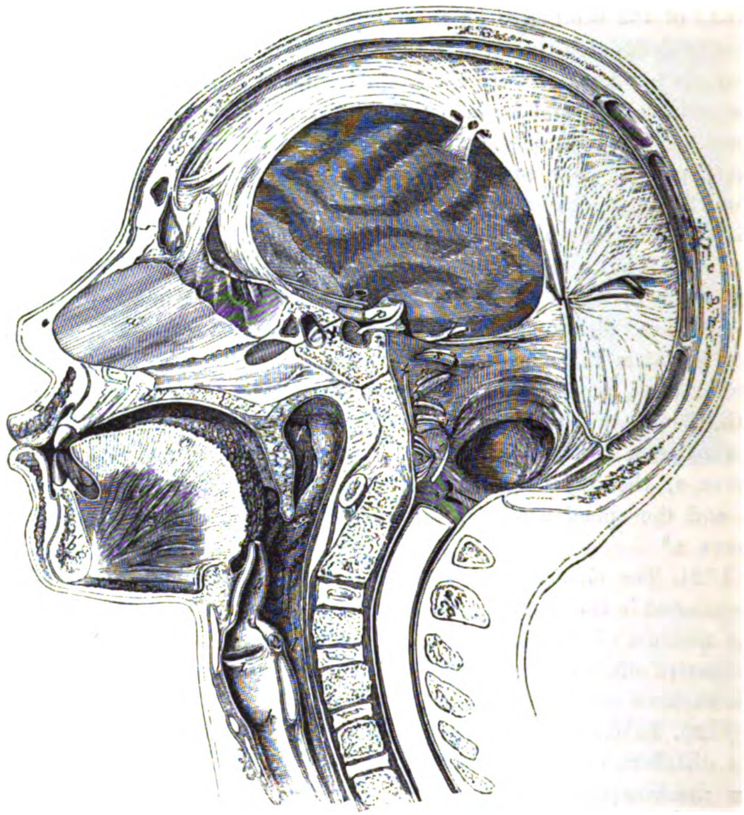
the superior (*s*, Fig. 259), internal (*i*, Fig. 259), and inferior rectus, and the inferior oblique muscle of the eye (*m*, Fig. 259); and supplies the short root of the optic or lenticular ganglion, which gives rise to the ciliary

FIG. 337.



nerves. These pass—amongst other places—to the iris, the median aperture of which is formed by the pupil (*c* Fig. 150, p. 273). In this way, the motor oculi nerve is enabled to assist in the production of those movements on which the enlargement or diminution of the pupil depends. In some exceptional instances two other muscles of the orbital cavity,—namely, the external rectus (*n*, Fig. 259) and the superior oblique (*e o*, Fig. 259), —receive, besides other nervous fibres, twigs of this cerebral nerve.

1727. Experiments on newly killed animals will easily convince us that the whole of the organs of movement supplied by this nerve are thrown into contraction when it is suitably stimulated. But it has been often disputed, whether it is a purely motor or a mixed (§ 1718) nerve. For when it has been laid bare and irritated at its cerebral origin (§ 1722),

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many experimenters have observed expressions of pain. And although these have not been noticed by others, still the great injuries implied in the observation throw doubts upon all negative results.

1728. The fourth or trochlear nerve (*r*, Fig. 337) passes to the superior oblique muscle of the eye (*o*, Fig. 259, p. 429). Its motor influence may often be verified in the dead body.

1729. The fifth or trigeminal nerve (*s*, Fig. 337) arises by two roots, a larger (*v*, Fig. 322, p. 484), and a smaller (*w*). The greater part of the primitive fibres of the former subsequently enlarge to form the Gasserian ganglion (*x*). The whole nerve then divides into three chief branches; the ophthalmic, the superior maxillary, and the inferior maxillary, divisions of the fifth.

1730. The two roots of the trigeminal nerve have often been compared to the double root of a spinal nerve (§ 1720). Here the larger (*v*, Fig. 322) would correspond to the posterior, and the smaller (*w*) to the anterior, root of a spinal nerve; the former containing only sensitive, and the latter only motor, fibres.

1731. The results observed in recently killed animals appear so far to sustain this view, as that irritation of the larger root causes no movement in those striped muscles which its branches penetrate, while stimulating the smaller root gives rise to vigorous contractions of the muscles of mastication (§ 366). Still we ought not to forget that many structures which are moved involuntarily, and are provided with unstriped muscular fibre (§ 1231),—such as the ducts of the lachrymal glands (§ 890),—are supplied by twigs which come from the ophthalmic branch,—*i.e.*, to all appearance, from the larger portion of the root. On the other hand, vivisection fails to certify that the small root originally contains no sensitive fibres.

1732. Much of the tactile sensibility possessed by the organs of the senses, and by the skin of the face, is due to the trigeminal nerve. Its ophthalmic division (*y*, Fig. 322, p. 484) supplies the lachrymal gland; the inner part of the globe of the eye; the conjunctiva (*d*, Fig. 150, p. 273); a large part of the mucous membrane of the nose (Fig. 322, p. 484) and its supplementary cavities; together with the skin of the forehead, the anterior part of the skull, the upper eyelid, and a great part of the outer surface of the nose. The superior maxillary branch (*z*, Fig. 322, p. 484) supplies the remainder of the mucous membrane of the nose, and of its supplementary cavities; a considerable extent of the mucous membrane of the Eustachian tubes, the upper part of the pharynx (*f*, Fig. 322), the soft palate (*u*), the tissues of its neighbourhood, the membrane covering the hard palate (*h*), the interior of the upper jaw with its gums and teeth, the skin of the lower eyelid; a great part of the middle of the nose, and of its inferior half; the surface of the cheeks as far as the temples, and of the upper lip. The inferior maxillary branch (*a*,′ Fig. 322, p. 484)

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supplies the skin of the temples, of part of the external ear, of the lower part of the face and the lower lip; the inferior surface of the cavity of the mouth; the gum and teeth of the lower jaw; and the greater part of the surface of the tongue. The fibres which pass to all these organs effect tactile sensations. The motor fibres of the third branch of the trigeminal nerve govern the more important muscles of mastication (the temporal, masseter, and pterygoids); together with some other muscles of the hyoid bone (the mylo-hyoid, and anterior belly of the digastric), and the tensor tympani (§ 1585) of the tympanic cavity.

1733. Each lateral half of the head receives its several branches from the trigeminal nerve of the same side. The branches of the right nerve do not pass over to the left side, nor do those of the left towards the right. Hence paralysis of the right nerve only affects the corresponding organs of the same side. The distinction is very marked; the loss of sensibility being limited to the right half of the upper or lower lip:—a fact which shows that there is very little transit of fibres from one side to the other.

1734. The sixth nerve (*t*, Fig. 337, p. 512) supplies the external rectus muscle (*n*, Fig. 259, p. 429) with motor fibres. Occasionally, it also gives off twigs to the optic ganglion (§ 1726); as well as to other muscles of the eye.

1735. While the skin of the face derives its chief sensitive fibres from the trigeminal nerve (§ 1732), the movements of the features are regulated by the facial nerve (*u*, Fig. 337, p. 512). This governs the muscles of the face and external ear, the stapedius in the tympanum, and some of the muscles of the neck (the stylo-hyoid, the posterior belly of the digastric, and the platysma myoides). Filaments also pass from it to the muscles of the soft palate. Irritation of the roots of the facial nerve in the newly-killed animal excites all these parts to contraction. At present, the roots of the facial nerve cannot be proved to enclose sensitive fibres. But it certainly receives many such elements during its subsequent course. Hence its trunk, on emerging from beneath the ear, belongs to the class of mixed nerves. Still the number of its motor fibres remains greatly predominant.

1736. Each of the two facial nerves is also distributed solely to its corresponding half of the head. In man, it frequently happens that one of these nerves is seized with temporary or permanent paralysis. Under such circumstances, the corresponding muscles of the face are deprived of their action. The effect of this is to destroy all the expression of the physiognomy, and the play of the features. An additional influence is exercised by the still active contractile structures of the other side. The muscles of the right half of the face are antagonized (§ 1309) by those of the left. And, under normal circumstances, each side is, to a certain extent, held in check by the other; so that all

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parts of the face are kept in lateral symmetry. The median line thus forms a straight line;—which is, as it were, a graphic 0 that forms the sum of these positive and negative values. So that the paralysis of the right facial nerve removes an important force which formerly opposed the elastic or vital contraction of the left facial muscles. Hence the mouth is often drawn towards the left or healthy side.

1737. The auditory nerve (*v*, Fig. 337, p. 512) conducts the impressions of hearing. In it, as in the olfactory and optic nerves (§ 1724), it is impossible to detect any fibres sensitive to pain.

1738. The functions of the glosso-pharyngeal nerve (*w*, Fig. 337) are very variously interpreted. The site of their origin and termination, and the doubtful manner in which animals express their sensations, lead to many indistinct phenomena, which we can only judge of subjectively.

1739. When the glosso-pharyngeal nerve of a dog or other domestic animal is examined immediately after its exit from the skull, we frequently get evident signs of pain. From this it has been inferred, that sensitive fibres are originally present. But the nervous trunk emerges from a very sensitive part of the medulla oblongata, the action of which may therefore be easily confounded with that of the glosso-pharyngeal nerve. At any rate, however, the glosso-pharyngeal does not belong to that class of nerves which is chiefly sensitive.

1740. On stimulating the smaller root of this part of the eighth nerve in newly-killed calves or cats, Volkmann has observed contractions of some of the pharyngeal muscles (the stylo-pharyngeus, and constrictor faucium medius). Still this motor influence cannot be compared with that of the vagus and accessory nerves. For instance, it often happens that irritation of the pneumogastric and accessory causes vigorous contractions, after the glosso-pharyngeal has long ceased to afford any. Hence many observers have been unable to verify the motor influence of this nerve.

1741. These facts sufficiently prove, that the greater part of the glosso-pharyngeal nerve is composed of neither sensitive nor motor elements. On the other hand, experiment shows it to be a sensuous nerve, which is destined to effect the true sensations of taste. The extent of this part of its function is at present the main object of dispute.

1742. We will regard the tongue as the special representative of the organ of taste (§ 1633). This organ is chiefly supplied by branches from three nerves—the trigeminal (*s*, Fig. 337), the glosso-pharyngeal (*w*), and the hypoglossal (*z*). All observations unite to state that the manifold movements of the tongue are due to the hypoglossal nerve (*f*, Fig. 323, p. 489); while the most important gustative impressions are effected by the glosso-pharyngeal. But many consider the latter the sole nerve of taste; and regard the trigeminal nerve as only effecting

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sensations of touch and pain. While others suppose it to be also capable of recognizing true sapid impressions.

1743. Repeated observations on living mammalia speak with increasing certainty to the fact, that the glosso-pharyngeal is the sensuous, and the trigeminal the sensitive, nerve of the tongue and most of the other organs of taste. Some instances of paralysis of the trigeminal nerve in the human subject may be understood in this sense. And we must not forget that many impressions, which are ordinarily considered sensations of taste, will be assigned to the sense of touch on a more careful examination (§ 1630).

1744. The vagus nerve (*x*, Fig. 337, p. 512) swells into a ganglion shortly after its origin. Here a number of fibres of the spinal accessory (*y*), are apposed to those of the pneumogastric, and proceed onwards with the branches of the latter nerve. Hence most of the branches of the vagus contain a mixture of fibres from the pneumogastric and the spinal accessory nerves.

1745. An attempt has been made to compare the roots of these two nerves with the larger and smaller division of the trigeminal nerve (§ 1730), or with the two roots of a spinal nerve. The vagus is supposed to be a purely sensitive nerve, and the spinal accessory an exclusively motor one. But recent experiments show that, when the filamentous roots of the vagus of a newly-killed animal are cut through at their origin from the medulla oblongata, their irritation can cause various muscles to contract. And some observers assert that the upper rootlets of the spinal accessory give rise to pain. Now since experiments on the living animal establish beyond all doubt that the vagus is sensitive, and the spinal accessory motor, it would seem that both of these nerves possess mixed qualities. But we shall hereafter become acquainted with some experiments which perhaps oppose this conclusion.

1746. On irritating the roots of the vagus in a rabbit, the animal shrieks with pain. When the same nerve is pinched in a newly-killed dog, vigorous contractions of the soft palate, the œsophagus, and the stomach, often follow. It may be further proved, that the roots of the pneumogastric nerve exert an important influence on the functions of the heart. The small muscles of the larynx are undoubtedly governed by those trunks which proceed from the union of the vagus and accessory nerves (§ 1744). Many assert that stimulating the roots of the pneumogastric in recently killed animals causes these parts to contract—while others make the same statement of the spinal accessory. This contradiction may be due to two causes. Some of these bundles, which lie midway between the vagus and accessory, may be assigned to either nerve, according to the judgment of the observer. In addition to this, we shall see that there are many facts which indicate that a sort of transfer here occurs:—so that a stimulus applied to an anterior rootlet of the

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pneumogastric may excite the action of other fibres, and even of those which belong to the accessory nerve.

1747. Numerous twigs of the vagus pass to the pharygneal plexus, on which much of the sensation and motion of the soft palate and pharynx depends. The œsophageal plexuses have similar anatomical and physiological relations. So that the united actions of the vagus and accessory exert a great influence on the mechanism of deglutition. Section of the cervical descending trunks of both pneumogastric nerves (*h*, Fig. 101, p. 187) is soon followed by difficulty of swallowing; and fragments of the food easily pass into the larynx and trachea (§ 372). The œsophagus not unfrequently becomes distended with alimentary matters. And in dogs and cats, a remarkable inclination to vomit is generally superadded, especially when the stomach is full.

1748. Each side of the larynx receives two branches from the cervical trunk of the vagus (*h*, Fig. 101). The superior laryngeal branch is given off above the larynx. The inferior one comes up out of the thorax, and then ascends along the trachea (near *k*, Fig. 101), to enter the larynx. Both are nerves of a mixed nature; but the superior is chiefly sensitive, and the inferior chiefly motor. The former supplies but a small part of the muscular structures of the larynx and the adjoining pharynx (the crico-thyroid, *b*, Fig. 253, p. 419, and *h*, Fig. 71, p. 127); while the latter is distributed to the remaining small muscles of the larynx (the crico-arytænoideus lateralis, *c*, Fig. 254, p. 419; the crico-arytænoideus posticus, *b*; the thyro-arytænoid, *d*; the arytænoideus transversus, *e*, and obliquus *f*). This distribution may also be established physiologically, by irritating these nerves in the newly killed animal. But their mere anatomy is less conclusive; for the superior and inferior laryngeal branches are so united to each other in the interior of the larynx, that it is impossible to demonstrate the course of their several fibres. The sensitive elements are chiefly distributed to the mucous membrane of the larynx, but probably also form a partial supply for that of the adjoining pharynx.

1749. The sensibility of the mucous membrane of the trachea, and the contraction which follows an artificial irritation of this tube (§ 1306), are also dependent upon the cervical trunk of the vagus. The numerous branches which it gives off to the pulmonic plexuses in the thorax, and (through these) to the lungs themselves, exert a considerable influence on the sensation and motion of these important parts of the respiratory apparatus. Hence the two vagi nerves can effect great changes in the function of respiration.

1750. When the two inferior laryngeal nerves, or the cervical trunks of the vagus, are cut through in a new-born animal, it soon dies of suffocation. But if a fistulous opening be at the same time made into its trachea (§ 1414), life may be maintained for a while. Older animals

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can better resist this injury; so as to live many hours or days. The above experiment proves that the speedy death of the young mammal depends upon some obstacle to respiration situate above the trachea. It is, in fact, caused by the circumstance, that on the paralysis of the laryngeal muscles, the vocal cords shut up like a valve, and thus close the glottis. This produces a mechanical obstacle to respiration (§ 738), which can be obviated by a tracheal fistula.

1751. Although young animals in whom an artificial respiratory aperture has been made, remain alive, and older ones do so even without this assistance, still both die, at latest, a few days after the infliction of this injury on the nerves. For it is followed by a degeneration of the lungs, which gradually undermines and destroys life. Many observers conclude, with Schiff, that the paralysis of the vagi seriously disturbs the nutrition of the lungs, and causes more or less inflammatory phenomena, which are accompanied by peculiar exsudations. Others, with Traube, attribute the whole result to mechanico-chemical causes. They suppose that the food and mucus which pass from the commencement of the œsophagus into the trachea and bronchi (§ 1747) irritate the lungs, and thus gradually cause their degeneration.

1752. On compressing the cervical trunk of the vagus in a newly killed mammal, some muscular bundles of the ventricles of the quiescent heart often contract anew. This is best seen in an experiment introduced by Ed. Weber and Budge. It answers equally well in mammals, birds, amphibia, and fishes. But since it is most easily made upon frogs, we will describe the phenomena as seen in this animal.

1753. At *A*, Fig. 338, is the heart of a frog, turned back, and transfixed with a needle; and at *c* is the trunk of its left vagus. This gives off the large cardiac branch *f*; which, with the one opposite, then forms a ganglionic plexus in the neighbourhood of the auricle.

1754. When the shocks of the electro-magnetic machine (§ 248) are made to act upon *f* or *c* in a newly-killed (and still highly sensitive) animal, the pulsation of its heart is instantly brought to a stand-still. If the electrical action be not continued too long, the state of diastole (§ 576) will last during the whole time of the experiment. But if it be continued, the heart after some time recommences beating. The roots of the vagus or accessory nerve (*y*, Fig. 337, p. 512) lead to what are essentially the same results.

1755. When the cervical trunk of the pneumogastric nerve of a newly killed mammal is subjected to mechanical, chemical, or galvanic irritation, movements are often seen in its stomach. After section of this nerve in the living dog, it has sometimes been remarked that, although the unhappy animal does not seek after food, still it occasionally devours large quantities of that which is offered to it. Hence it has been sup-

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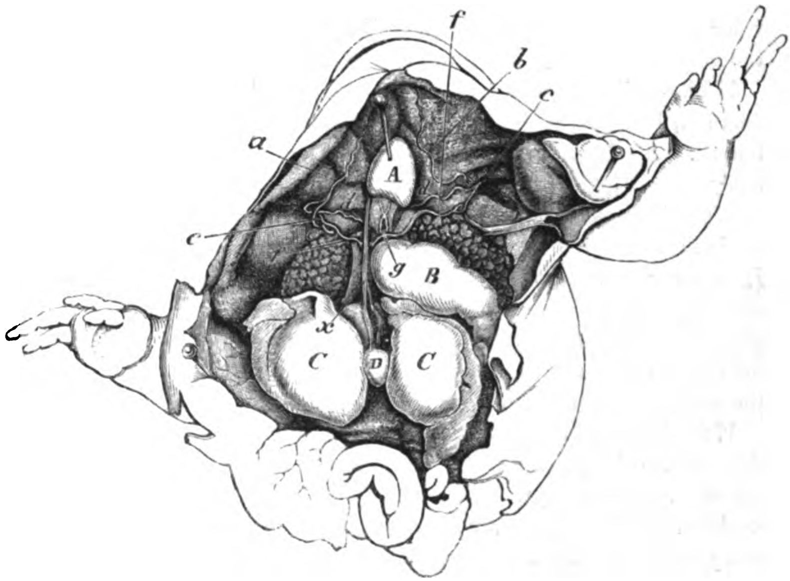
posed that the paralysis of the sensitive fibres of the vagus prevents the feelings of hunger and satiety. But future researches must decide as to the accuracy of this conclusion.

FIG. 338.



1756. Section of both vagi in the neck of an older (§ 1750) dog or rabbit, seriously disturbs the process of gastric digestion. This is always rendered slower. Some portions of the food, such as hard meat, appear to be scarcely attacked at all. But the gastric contents may still have a strong acid reaction; and the acidulated artificial digestive fluid which has been prepared from the stomach of an animal thus operated upon, can effect the rapid solution of coagulated albumen (§ 439). So that those organic contactive substances which we include under the name of pepsine (§ 299), are still present. In contradiction to this, however, many physiologists deny that an acid gastric juice is secreted. According to their statements, mechanical irritation of the gastric mucous membrane of dogs in whose stomachs a fistula has been established, affords, under such circumstances, an alkaline fluid.

1757. The cervical trunk of the vagus of recently killed dogs or rabbits can also excite the action of the small or large intestines. This fact is explained by the circumstance, that the gastric plexus which both vagi assist to form, gives off branches that enter (either directly or by means of the solar plexus) into the trunks that supply those segments of the alimentary canal.

1758. The external branch of the spinal accessory nerve—that is, the

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part of this nerve which does not penetrate the branches of the pneumogastric, but only receives a few of its sensitive fibres—supplies some muscles of the neck and back (the sterno-cleido-mastoid, *a b*, Fig. 236, p. 398, and the trapezius, *c*). When both spinal accessory nerves are torn out in a cat or rabbit, so that all their roots are destroyed, the voice of the animal almost or quite disappears. But it would seem that the movements of deglutition can still be executed as vigorously as before.

1759. We have already (§ 1742) seen that the ninth or hypoglossal nerve (*z*, Fig. 337, p. 512) is the chief agent of the movements of the tongue. All its roots appear to contain motor fibres. But it is probably not altogether devoid of sensitive filaments.

1760. This cerebral nerve gives off a peculiar branch, the descendens noni, in which the superior cervical nerves take an important share. It is the motor nerve of some of the cervical muscles (the omo-hyoid, sterno-hyoid, and sterno-thyroid); and, in man, it also unites with the phrenic or diaphragmatic nerve. The latter, which is given off by the inferior cervical nerves, receives the fibres just mentioned, and governs the contractions of the diaphragm (*m n o*, Fig. 9, p. 34).

1761. The main trunk of the sympathetic nerve descends on each side of the body; from the head, along the neck, thorax, and abdomen, to the coccyx. It is chiefly distinguished by its offering a double row of ganglia, which in the chest and belly are repeated at every vertebra. Its roots are formed by numerous filaments derived from all the spinal, and most of the cerebral, nerves. And in the opposite direction it gives off a large number of branches; which subsequently enter into ganglia, and assist to supply the viscera of the trunk, many of the blood-vessels, numerous glands, and other textures. Similar ganglia are present in many other nerves,—such as the posterior roots of the spinal nerves (§ 1719), part of the nerves of the eye (§ 1726), and the trunks and some of the branches of the trigeminal (§ 1729), the vagus (§ 1744), and other cerebral nerves. All of these swellings are often comprehended under the name of the ganglionic system. But the sympathetic being especially distinguished by the number of its ganglia, many authors limit this expression to the two cords of this nerve, together with the swellings which are connected with them.

1762. These enlargements of the nerves are due to the addition of a new element, the ganglion-corpuscle (§ 1692), to the nerve fibre. For example, Fig. 339 represents a ganglion from the posterior root of a cat's cervical nerve, slightly magnified. Here numerous corpuscles are seen deposited around the bundles of primitive nerve-fibres which penetrate the ganglion. Some of these corpuscles (more strongly magnified) are represented in Fig. 340, in that isolated state in which they may often be found after a ganglion (Tab. V. Fig. 74) has been torn up.

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1763. Fine sections which exhibit these structures in their natural position lead directly to the conviction, that they do not lie free between the nerve-fibres, but that they everywhere possess a proper sheath, which has probably a certain physiological import. At the margin of the ganglion we frequently find a few corpuscles having the appearance represented in Fig. 341. The whole is surrounded by a concentric and apparently fibrous membrane, on which are remarked numerous oval

FIG. 339.

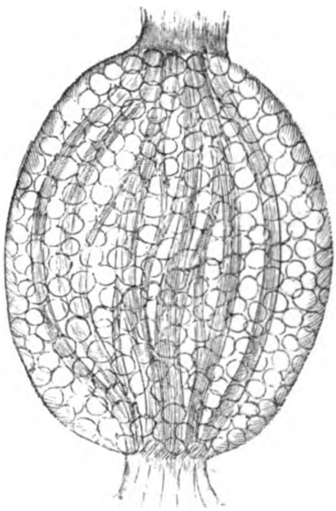


FIG. 340.

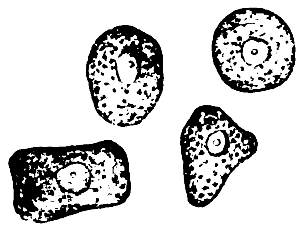
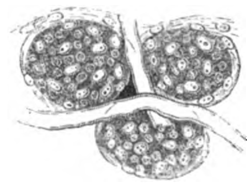


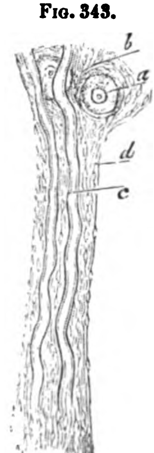
FIG. 341.

FIG. 342.



nuclei. These nuclear structures sometimes also cover the free surface of the ganglion-corpuscle; so as to prevent all recognition of its substance, its nucleus, or its nucleolus (Tab. V. Fig. 71, *a b c*). This state may be illustrated by Fig. 342. Here some medullary primitive fibres are also seen winding between the ganglion-corpuscles. These are termed circumferential fibres, in contradistinction to those represented in Fig. 339, which pass through the ganglion in bundles, to run in the trunk of the sympathetic or its subordinate branches.

FIG. 343.



1764. A very fine section of the ganglion and nerve of a mammal at their point of union with each other sometimes affords the view sought to be represented in Fig. 343 (compare Tab. V. Fig. 71). Here the ganglion-corpuscle (*a*) is surrounded by the sheaths (*b*) formerly mentioned (§ 1763). But these are continued (at *d*) into the nerve, forming what are sometimes called vaginal processes of the ganglion-corpuscles. Between these run nervefibres with distinctly medullary contents (*c*). Hence such a fragment of a nerve at its connection with the gang-

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lion frequently shows both these elements together; the medullary primitive fibres (*a*, Fig. 344), and the vaginal processes provided with nuclei (*b*).

1765. A nerve which chiefly consists of the ordinary medullary fibres appears to the naked eye of a brilliant white. But when these are mixed with considerable quantities of such vaginal processes, the whole possesses, when fresh, a whitish-grey colour; which is soon converted into a reddish-grey hue by putrefaction. The trunk of the sympathetic is then generally softer. Hence branches of this kind have been named grey or gelatinous nerves; while the vaginal processes themselves are frequently called organic fibres, or fibres of Remak. But their appearance indicates that they belong to the group of areolar tissues, or of investing substances. Their physiological import is at present quite unknown.

FIG. 344.

1766. On comparing a purely motor nerve—for example, the anterior root of a spinal nerve—with a branch of the sympathetic, the former is seen to contain a great many large nerve-fibres (Tab. V. Fig. 68, *b*), while the latter is chiefly composed of small ones (Tab. V. Fig. 68, *c*). Bidder and Volkmann have supposed that this difference of diameter indicates two special classes of fibres:—that the larger proceed from the brain and spinal cord, and may be thence called cerebro-spinal or animal nervous elements; while the smaller arise from the ganglia of the peripheric part of the nervous system, and especially of the sympathetic, and ought therefore to be regarded as special sympathetic fibres. But recent researches show that there is no absolute distinction between these two kinds of fibres. Both possess the same medullary content;—which exhibits varicose swellings (Tab. V. Fig. 68, *d*) as the result of injury or other abnormal circumstances, and which coagulates sooner or later after death (Tab. V. Fig. 69). Many of their fibres are of such a medium diameter, that we may allot them to either the large or the small variety at will (Tab. V. Fig. 68, *d*). And although the sympathetic is chiefly composed of fine fibres, still large ones may frequently be found in it: while, conversely, small fibres are often seen in the various cerebro-spinal nerves. And the diameter of the same fibre often diminishes in its course;—so that, for instance, most of the terminal plexuses exhibit great numbers of the smaller fibres. Hence we have no right to suppose that every fine fibre met with in any particular nerve necessarily belongs to the sympathetic.

1767. On examining an entire thoracic ganglion of the sympathetic of a cat under a low magnifying power, we observe appearances like those represented in Fig. 345. Here the greater part of the fibrous

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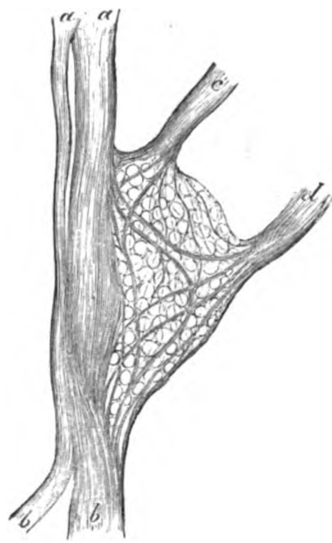
substance of the sympathetic trunk *a b* descends vertically. The ganglion itself is traversed by other bundles of filaments, which come from its roots *c* and *d*, and are subsequently apposed to the fibrous substance of the sympathetic trunk, or its branches. In one word, many of the fibres only come into mediate contact with the ganglion-corpuscles.

The finer fibrillation that obtains in the ganglia of fishes leads to many peculiarities, which were first recognized by Robin, Wagner, and Bidder. For example, on tearing up the Gasserian ganglion (*x*, Fig. 322, p. 484) of a newly killed eelpout (*Gadus lota*) into extremely small fragments, we often meet with appearances such as are represented in Tab. V. Fig. 72. The ganglion-corpuscle (*a*) is connected above and below with a process (*b* and *c*) which is obviously a medullary primitive fibre. When putrefaction has advanced somewhat further, such specimens are still more easily found. Here the coagulation of the contents, and the spontaneous decomposition of the remainder of the nerve, frequently lead to appearances such as are represented by Tab. V. Fig. 73.

FIG. 345.



1768. The appearances just described may easily be verified in many fishes. The eelpout, the pike, the eel, and most of the cartilaginous fishes, are better adapted to this purpose than the Cyprinoid genus. And the Gasserian ganglion, or that of the root of a spinal nerve, is preferable to the ganglion of the vagus; while this is better than the solar ganglion of the abdominal viscera. In fishes, it is evident that the medullary process of nerve is never limited to one side only, but that at least two such proceed from every ganglion-corpuscle.

1769. The facts just described may be explained by supposing a primitive nerve-fibre (Tab. V. Fig. 72, *b c*) to be interrupted by a ganglion-corpuscle (*a*) in the middle of its course. But the appearances hitherto known are very far from clearing up the whole bearings of the facts. For example, it becomes a question what is the relation of the medullary content of the nerves to the very different substance of the ganglion-corpuscles;—whether it is a true proximity, or otherwise;—whether the ganglion-corpuscle floats in a modified nervous content, or whether the latter only occupies its neighbourhood. In any case it would seem that the membrane which encloses the nervous medulla dilates to receive the

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ganglion-corpuscle. It is also possible that the same nerve-fibre is interrupted by a second corpuscle at a further point of its course.

1770. In reptiles, birds, and mammals, there are great obstacles to a satisfactory examination of these structures. For instance, a fine section of a sympathetic ganglion from a mammal shows ganglion-corpuscles (*a*, Fig. 346), none of which are connected with any of the true nerve-fibres (*b*) seen here. In some of the smaller ganglia of the frog, it may be proved that there are far more corpuscles than fibres. It is therefore certain that some of the ganglion-corpuscles are not interposed between nerve-fibres. It is true that in other ganglia of the frog double processes may be detected. But no medullary content can be verified in their interior. Koelliker and others have often observed a medullary fibre proceeding from one side of a ganglion-corpuscle. But against these observations, however frequently confirmed, we have a right to object, that the second process may either have been torn off in preparing the specimen, or concealed by its unfavourable position. In point of fact, a prolonged search in such preparations will sometimes enable us to find it.

FIG. 346.

1771. We have seen (§ 1761) that numerous branches connect the trunk of the sympathetic with the cerebral and spinal nerves. During more than a hundred years the import of these intervening structures has been made the subject of a number of conflicting theories. Many have supposed, with Haller and his school, that the primitive fibres contained in these connecting cords arise from the cerebro-spinal nerves (§ 1690), pass through the ganglion, and subsequently radiate into its branches. According to this view, the sympathetic would be essentially a cerebro-spinal nerve;—presided over by the brain and spinal cord, just as the peripheric organs are by the other nerves. Hence the physiological peculiarities of its branches (which we shall hereafter describe) would depend solely on the numerous ganglia that are interposed in their course. Others follow the theory started by Petit, and developed by Bichat. According to it, the sympathetic or ganglionic system constitutes a nervous system which is independent of the brain and spinal cord. Its peculiar fibres chiefly supply the intestines, the blood-vessels, the glands, and —in general terms—all those tissues which are destined to subserve the phenomenon of nutrition, and the unconscious and involuntary functions. It is thus a special visceral, vegetative, or organic nervous system; which has an authority independent of, and co-equal with, its animal counterpart. The latter is composed of the cerebro-spinal nerves,

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which effect the conscious feelings of sensation and pain, and the voluntary movements.

1772. The question must be examined from two points of view—an anatomical and a physiological. Most of the ganglia (§ 1767) are visibly traversed by some fibres or bundles from their roots. Indeed, in the smaller vertebrata, large fibres may be followed through a number of ganglia; for instance, through those of the trunk and visceral branches of the sympathetic in the thorax. These facts sufficiently indicate that the sympathetic does not form a perfectly independent system :—a proposition which they would indeed incontestably prove, were it possible to follow the whole course of the fibres under the microscope.

1773. We may frequently observe that the total bulk of the branches which emerge from a ganglion is much greater than that of the roots which enter it. This increase of diameter is partly referrible to the vaginal processes (§ 1764), which occur in large quantity in mammals and birds. But it also occurs in amphibia and fishes, in whom the proportion of these supplementary structures is much smaller. Here it may be distinctly shown that the branches given off from a ganglion contain more primitive fibres than its roots. Bidder and Volkmann have especially adduced this difference of number in support of the anatomical independence of the ganglionic system; and regard it as a proof that there are special sympathetic, organic, vegetative, or ganglionic fibres; which arise in the ganglia, and which pass, partly in the peripheric direction, and partly towards the cerebro-spinal centre.

1774. This real or apparent multiplication of fibres may be due to a variety of causes. Many nerve-fibres do not run straight to their termination, but rather present appearances like those with which we have already been made acquainted in the terminal plexuses (§ 1700). The fibres pass for a certain distance in a given nerve, and then turning round, come back in the same nerve, to take another and a further path. This peculiar course is best exemplified by the thoracic portion of the vagus of the mouse. Other examples are now and then seen in the sympathetic trunk of the frog. It is obvious that these arched fibres will be counted twice over in the branch in which they lie. Hence the apparent multiplication of fibres which occurs in the branches of the ganglia may be partially due to this circumstance. Still all careful researches indicate that it only occurs to a limited extent, while the number of fibres is really increased.

1775. Koelliker, who especially supports the view of a one-sided origin of fibres, concludes from his observations that the sympathetic is partly dependent, but partly independent. The cerebro-spinal fibres which pass through the ganglia place them in certain relations with the brain and spinal cord; while the ganglionic fibres which proceed from one side of the corpuscles form the independent elements of the sym-

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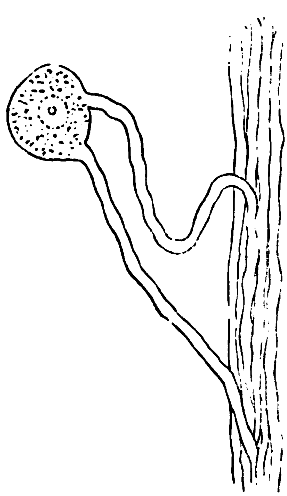
pathetic and its ganglia. This view at the same time explains that increase in the number of fibres, which these swellings exhibit.

1776. But we have already seen (§ 1770) that there are many considerations which militate against the view of a one-sided origin of fibres. In the ganglia of the fish's vagus, the greater thickness of the emergent trunk is very striking. In spite of this, however, it is only in suspicious preparations that we see one-sided processes of the corpuscles; and even here they are by no means frequent. And recent microscopic researches suggest other explanations of the multiplication of fibres.

1777. Those ganglion-corpuscles which only give origin to an upper and a lower medullary fibre, are most frequently seen in fishes. Now, if it could be proved that one process (Tab. V. Fig. 72, *b*) was connected with the brain or spinal cord, while the second, (*c*) took a further and peripheric course, it would be obvious that the interposition of ganglion corpuscles would allow no multiplication whatever of the fibres. But we sometimes find that the two medullary fibres do not proceed from the opposite poles (Tab. V. Figs. 72, 73), but from the same side, of the ganglion corpuscle. For example, in a ganglion of the root of the spinal cord in an eelpout, Bidder remarked two such processes entering the same nerve in a peripheric direction, as shown by Fig. 347. This would not only afford another explanation of the multiplication of fibres; but would also support the theory of independent ganglionic fibres.

FIG. 347.



But many facts are opposed to this explanation. The appearances shown in Fig. 347 are extremely rare. Many observers have never been able to see them, in spite of the most industrious search :—while the frequency of the supposed ganglionic fibres ought often to give rise to appearances of this kind. And, even apart from this, it is doubtful whether the two fibres which enter the nerve in the peripheric direction really take such a course.

1778. There are other facts which better account for the increase of fibres. It is true that in the fish we generally see but two processes proceeding from one ganglion-corpuscle. But in the dog-fish, Stannius has observed a nervous vesicle giving off one fibre on one side, and two on the other. The drawing he has given of that instance[46]) appears to indicate a division of the primitive fibre close to the ganglion-corpuscle. Traces of division of

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the fibres have also been seen by the author in various ganglia. These facts suggest that the multiplication of fibres may be due to their dividing in the ganglia, as well as in the free nerves.

1779. A second cause may perhaps be found in the possibility, that many of the sheaths which proceed from all sides of the ganglion-corpuscles become filled with medullary substance. Some of the grey nerves (§ 1765)—for example, those which arise from the gastric ganglion of mammals — occasionally exhibit no medullary contents whatever, even after treatment with caustic potash or soda. In other cases the application of these reagents causes its appearance. The neurilemma or investing membrane, which is thin, clear, and transparent in the fibres of the ordinary cerebro-spinal nerves, appears thicker, less transparent, and of a greyish-white or yellowish-red colour, in many branches of the ganglia. It therefore depends upon accidental circumstances whether its medullary content can or cannot be seen. Such membranes radiate on all sides from the ganglion-corpuscles, and even sometimes bifurcate (Tab. V. Fig. 74, *c d e*). And supposing that they sooner or later become filled with nervous medulla, this would permit any amount of multiplication of the true nerve-fibres, either in the central or peripheric direction.

1780. Hence in the present state of histology, the complete anatomical independency of the sympathetic or ganglionic system must be regarded as highly improbable. While, in spite of the most perfect anatomical dependence, the number of fibres might still undergo a considerable increase; either by their dividing, or by some of the vaginal processes of the ganglion-corpuscles becoming filled with nervous medulla. At present we cannot demonstrate any special sympathetic fibres, which may be easily recognized as such. It is true that the stronger sheaths above mentioned (§ 1779) are most frequently found in the branches of the sympathetic trunk, or their subsequent ganglia. But they are often met with in the ganglia of the cerebro-spinal nerves. And their number varies with the age, species,—and perhaps even the individual peculiarities,—of the animal.

1781. The main argument for a physiological independence of the sympathetic or ganglionic system lies in the peculiar relations of most of those organs which are chiefly supplied by this part of the nervous system. All tactile stimulation of the thoracic and abdominal viscera, the blood-vessels, the glands, and other organs exclusively nutritive, passes unnoticed. And the will is equally incapable of exerting any immediate influence upon these organs. Now conscious perceptions and voluntary motions alike depend directly or indirectly upon the brain. And hence it would appear that the nervous tissues which conduct the phenomena of nutrition do not extend so far as this organ. Their centres lie in the sympathetic system, or in the ganglia

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generally:—that is, in parts which are remote from those which bring about the higher mental emotions.

1782. But many facts of daily experience testify against this view. Under abnormal circumstances, the intestines become the seat of acute pain; and irritations, which would otherwise pass unnoticed, give rise to the most unpleasant sensations. Hence, under certain morbid conditions, impressions are transferred to the organ of consciousness. So that there cannot be any insurmountable barrier between the ganglia and the brain. And, conversely, many of the stimuli which impinge on the most delicate organs of touch habitually fail to excite our consciousness. We scarcely ever notice the soft currents of air which play upon our skin, or the slight changes of temperature which are constantly occurring. Every instant, many delicate sensuous impressions escape our consciousness. We may therefore suppose, that the ganglia are capable of furnishing some collateral condition, which, under ordinary circumstances, renders conduction to the brain a matter of difficulty. And this supposition, which forms a complete explanation, is also compatible with the most perfect dependency upon the cerebro-spinal centre.

1783. Anatomy often teaches that the intestines are supplied not only by the sympathetic, but by cerebral nerves, and especially by the vagus. It is therefore not so much the independence of the sympathetic nerve, as that of the ganglionic system generally, which we have to consider. By experimenting upon those cerebral nerves which give off ganglionic branches to the viscera, we shall find that their roots, (which are chiefly connected with the medulla oblongata,) are capable of governing the motor, and even the sensitive, structures of these organs. The spinal nerves which give origin to the connections of the sympathetic (§ 1761) with the spinal cord, afford what are essentially similar results. Hence the complete physiological independence of the intestinal nerves with respect to the brain and spinal cord, can only be assumed with the aid of certain arbitrary collateral hypotheses.

1784. On irritating the denuded sympathetic trunk, or its intestinal branches, in a living mammal, it sometimes happens that no sensations of pain at first occur. But on prolonging the experiment, they appear quite unmistakeably. Now and then slight irritations are not responded to at all, while more violent attacks are vigorously so. The filaments (*c d*, Fig. 345, p. 523) which connect the trunk of the sympathetic to the spinal nerves are generally very sensitive. The ganglia themselves at first respond to irritation more slowly; and branches which come from a series of ganglia, still more faintly. These facts seem quite to confirm the interpretation already given (§ 1782): namely, that the ganglion-corpuscles oppose the undisturbed conduction of a stimulus. We must, however, remember that the posterior roots of the

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spinal nerves are provided with ganglia (§ 1719), and yet transmit tactile impressions to the seat of consciousness with the greatest accuracy. Hence there are but two alternatives:—either this capacity of obstruction only pertains to particular ganglia, or the ganglion-corpuscles contained in the posterior roots of the spinal nerves are connected solely with those fibres which afford no tactile sensations.

1785. The number of ganglia in the cervical portion of the sympathetic trunk does not correspond to that of the vertebræ (§ 1761). In man and many mammalia, there are but two or three in this region; the superior cervical ganglion, the middle (which is less constant), and the inferior. The first of these gives off, amongst others, a number of fibres which are distributed in the head. This arrangement is remarkably illustrated by many physiological phenomena.

1786. In man and the rabbit, the cervical trunks of the sympathetic and vagus take a separate course. In the dog, they are more intimately united. On cutting through this common nerve in the upper half of a dog's neck, the aperture of the pupil (*c*, Fig. 150, p. 273) soon undergoes a considerable diminution in size, and remains in this state for weeks or months. The iris (*b*, Fig. 150, p. 273) can therefore be regulated by means of nerves from two sources. The common motor oculi (§ 1726) acts upon it by means of those fibres which pass through the optic ganglion and ciliary nerves; while the upper part of the united vagus and sympathetic acts through those of its own fibres which ascend towards the head. From experiments on rabbits, and from pathological observations on the human subject, it would seem that the iris derives nerves from this second source even in animals in whom the vagus and sympathetic nerves do not form a common trunk.

1787. We have seen (§ 1753) that the vagus nerve gives off a large number of filaments to the heart. The sympathetic also supplies numerous branches to the chief organ of the circulation. But comparative anatomy clearly indicates that the relations of these nerves to the viscera vary greatly in different animals. The same parts which, in higher animals, derive their branches from the sympathetic trunk, are, in the lower vertebrata, supplied by the vagus. This circumstance appears also to affect their physiological actions.

1788. However obvious the influence exerted by the vagus nerve on the heart of the frog (§ 1754), it is difficult to determine the precise action of the branches which are supplied to this organ from the sympathetic trunk. In mammalia, however, the two nerves offer a singular antagonism. On stimulating the cervical trunk of the vagus with the electro-magnetic machine (§ 248), the action of the heart is generally arrested. While, when the experiment is successfully repeated on the trunk or branches of the sympathetic, its pulsation is always accelerated. The same antagonism is often repeated by the roots of the

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vagus, and those of the sympathetic or the corresponding spinal nerves. Hence there is some peculiar difference, which the intervening ganglia can neither originally produce, nor subsequently remove,—at least not as regards the powerful stimulus of repeated electric shocks.

1789. The heart is chiefly distinguished by the fact, that its muscular substance undergoes an alternate contraction and relaxation at each successive moment (§ 576). And since these periodical variations of activity are repeated in an excised heart, it follows that they do not primarily depend on any of the nervous trunks which supply the organ. This fact has been regarded as proving the independency of the ganglionic system. The nerves which run in the interior of the (apparently single, but in reality double) auricle of the frog (§ 598), present minute ganglia, as do also most of the branches which enter the heart of the mammal. The independence of these has been supposed to explain why the excised heart may retain its activity many days after the removal of the brain and spinal cord.

1790. Although physiology cannot explain all the mysterious phenomena exhibited by the movements of the heart, it at any rate possesses sufficient facts to justify the rejection of this view. We can indeed prove that the extraordinary gulf which, on this assumption, would be interposed between the involuntary movements of the heart and those of other muscular structures, does not really exist.

1791. In the first place, alternate contraction and relaxation may also occur in the voluntary muscles of the trunk and limbs. When a frog is beheaded and skinned, the muscles of its fore-legs sometimes tremble for a long time. It is true that they do not present an uniform and definite rhythm like that of the heart. But they offer the same essential fact; viz., a repeated alternation of contraction and relaxation. And on dividing the chief nerves which supply the convulsed muscles, their contractions are often instantly arrested—a fact which proves that they do not originally depend upon the contractile tissues, but on the nerves by which these are governed.

1792. Similar alternating phenomena are sometimes seen in the diaphragm of mammalia. These, however, frequently continue after the extirpation of the trunk and branches of the diaphragmatic nerve. Now the diaphragm can be made to contract voluntarily, and there are no ganglia in the terminal plexus of its nerve. It therefore follows, that the continuous contractions of a muscle which is capable of being subjected to the will, do not necessarily require the aid of the nervous centre, or of ganglion-corpuscles. We shall also find that there are other facts which prove the same proposition with respect to the muscles of the limbs.

1793. A comparison of the lymphatic hearts (§ 550) with those of the blood-vessels, will carry us a step further. In the frog there is

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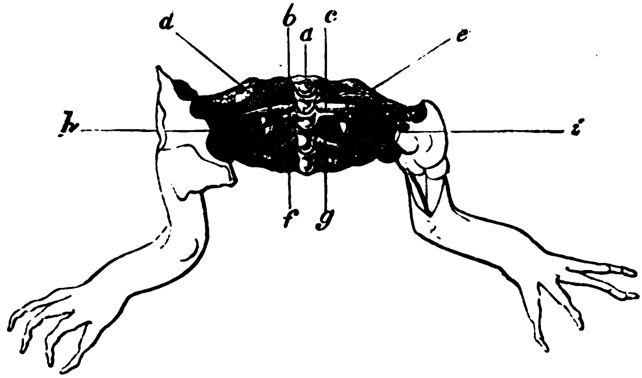
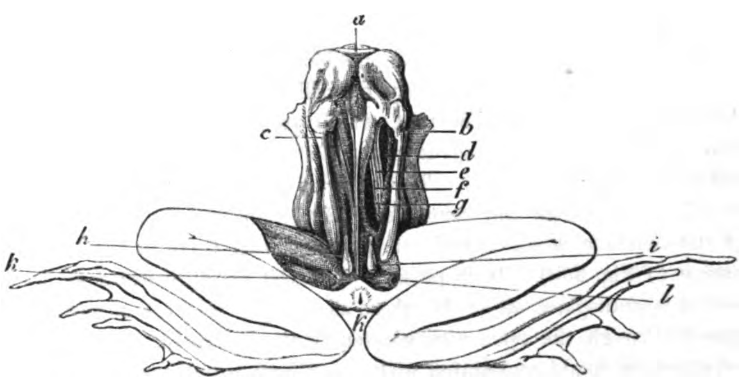
a pair of anterior lymph-hearts (*h i*, Fig. 348) each of which lies on a transverse process of the third vertebra (*b c*) within the abdominal

FIG. 348.



cavity; and a pair of posterior ones (*h i*, Fig. 349), which are placed immediately under the skin at the junction of the thigh with the

FIG. 349.



trunk,—where their pulsation may be recognized in a suitable position of the uninjured animal. All four derive their motor fibres from the spinal cord;—each of the two anterior from the third nerve of its own side, and each of the two posterior probably in great part from the tenth nerve (Fig. 336, p. 510). Hitherto ganglion-corpuscles have not been found in these nerves, either in the frog, or even in the large posterior lymphatic hearts of some snakes. If the spinal cord of a frog be destroyed, the posterior lymphatic hearts may still continue to beat for a certain time. But each of them then divides into a number of sacculi, which contract successively. And if cut out without any further injury, it may, under favourable circumstances, continue to beat for a long time.

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1794. On comparing these appearances with those presented by the blood-heart, we find that, even when excised from the body, the latter preserves its ordinary mode of contraction. Its pulsation may continue for hours, and even for 2½ days; while that of the excised lymph-heart has never been known to last longer than three hours in any experiment hitherto made.

1795. Hence whatever the chief cause of the rhythmic contraction, it does not necessarily imply the co-operation of the nervous centre, or of ganglion-corpuscles. The advantages (§ 1794) possessed by the vascular over the lymphatic heart are possibly due to its ganglia, or to other collateral causes.

1796. The excised frog's heart, which has ceased to beat of itself, may be excited to one or more contractions by a puncture with a needle, that appears only to irritate a limited locality. And to whatever point of the ventricle (*c d e*, Fig. 350) we apply it, the contraction still appears to begin in the auricle (*a b*). The systole of the ventricle then follows as an after-beat. It has therefore been supposed that the heart contains some arrangement, by means of which a direct irritation of any part is so conducted, distributed, and elaborated, as to result in an uniform beat of the whole organ. But it is also possible that the whole phenomenon depends merely on collateral mechanical conditions. Any gaseous or liquid current which passes over the internal surface of the heart, easily gives rise to a contraction that resembles a reflex movement (§ 1717). The auricles seem to be more susceptible in this respect than the ventricles. But their systole leads to a beat of the ventricle, which is intimately united with them at the transverse fissure (*f* Fig. 350). It is possible that the pressure exercised by the needle may displace air or blood, so as to give rise to a current, which passes through the open auriculo-ventricular aperture. Still we shall hereafter be made acquainted with some facts which are opposed to the general application of this theory.

FIG. 350.

1797. If a portion of the apex of the heart, *e*, be cut away, the ordinary rhythm of its pulsations may still remain. And the transverse section may even be made along *c d*, so as to leave but a small ring of ventricle, without causing any essential alteration. But if, on the other hand, the section be made exactly in the transverse fissure that separates the auricle *a b* from the ventricle *c d e*, the latter is frequently arrested, while the former continues to beat. Still, however energetic the influence thus exercised by the transverse fissure, we have no right to suppose it therefore necessary to the contraction of the whole ventricle. For even after this has been separated from the auricles, it may either continue to beat spontaneously, or may be artificially

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excited to a complete pulsation. But in the latter case, the excitability seems to diminish, the further we go from the apex towards the transverse fissure. On dividing the ventricle lengthwise, so as to begin with a small incision at the apex, and carry it towards the transverse fissure, both halves may at first continue to beat, although with unequal rhythm. But the subsequent increase of the injury arrests the action of one or both segments.

1798. However mysterious all these facts at present appear, still they suffice to show that even the physiological relations of the heart do not justify our assuming the independence of the sympathetic or ganglionic system. But there are other experiments even more decisively opposed to this supposition.

1799. We have already (§ 1752) seen that repeated electrical irritation of the roots of the vagus brings the heart of all vertebrata to a stand-still for a certain time. This state is a true diastole, having no resemblance whatever to a tonic systolic spasm. Indeed, the tension of the arterial blood is considerably diminished: although it finally remains at a considerable height. On pressing a limited portion of the ventricular surface at this instant, we get a rhythmic systole; which, as usual, begins at the auricle, and is afterwards repeated in the ventricle. When the electric stimulus is applied to the roots or trunk of the vagus, its action is at first local. But its effects afterwards extend to the heart, something like the way in which irritation of the sciatic nerve forces the gastrocnemii to contract. And that influence of local stimulus which was mentioned above, may perhaps be partially explained by another fact: — namely, that the peripheric segments of motor nerves are more easily excited than those which lie nearer the nervous centre.

1800. Assuming the sympathetic to derive its roots from the brain and spinal cord, we might expect that, under favourable circumstances, these would exert an influence on the heart. And, in point of fact, the heart of recently killed mammals may be excited to renewed action, not only through the spinal accessory, but also through the superior cervical nerves. In experiments upon frogs, Schiff found that the beat of the heart ceased soonest, after cutting through the roots of the fifth cerebral, the vagus, and the first spinal, nerves. While, on the other hand, if but one of these connections with the brain or spinal cord was left uninjured, the movement of the heart endured for a much longer time. Ravens died at once, on cutting through both their vagi, and tearing out the sympathetic ganglia on their brachial nerves.

1801. All this incontestably proves that the central roots of the nerves are capable of influencing the action of the heart. But the rhythmical character of the cardiac movement, and its continuance after excision of the heart, neither testify to the independence of the

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nervous ganglia, nor even imply a co-operation of the ganglion-corpuscles. It may be conjectured that all the circumstances just mentioned, are originally due to transfers of action, and to peculiar arrangement of muscular fibres (§ 597).

1802. The lungs derive their nerves from the vagus and sympathetic. The vagus may be proved to have the capacity of exciting the contractions of those muscular fibres which they contain (§ 1749). But it has hitherto been found impossible to determine the exact purpose fulfilled by the sympathetic fibres.

1803. Something similar to this obtains in the œsophagus:—where stimulation of the vagus again gives rise to energetic contractions (§ 1746), while that of the sympathetic produces either no results, or at most very doubtful ones.

1804. All those segments of the alimentary canal which occupy the cavity of the abdomen, can contract vigorously under the influence of the corresponding divisions of the sympathetic trunk, and their branches. The thoracic portion acts upon the small intestines, and even upon some parts of the large intestine. The lumbar portion governs the lower part of the alimentary canal; together with the urethra (*k l*, Fig. 154, p. 285), the bladder (*m*), the vas deferens (*w q*), the vesiculæ seminales (*x n*), the Fallopian tubes (*y z*, Fig. 119, p. 208), and the uterus (*x*).

1805. Experiments on the several spinal roots of the sympathetic show that they can excite contraction, not only in the iris (§ 1786) and the heart (§ 1788), but also in the abdominal and pelvic viscera just mentioned. Such observations acquaint us with a peculiar law:—viz., that the spinal roots which act upon a given organ do not lie at the same height with it, but at a certain distance above or below. Their fibres pass for some length with the ganglia and the trunks and branches connected with them, before finally radiating to their peripheric distribution. But this phenomenon is only a parallel to the relations of the cerebro-spinal nerves—most, if not all, of which exhibit something very similar.

1806. At present we know but little of those influences which the nervous system is capable of exercising on the local phenomena of circulation, secretion, and nutrition. Very few of these changes occur with sufficient constancy to allow of their being artificially produced, in accordance with known preliminary conditions. Many circumstances are partially explained by various hypotheses. But a complete and satisfactory theory will long remain impossible. Finally, we are ignorant whether the influences under consideration are not exerted by a special nervous tissue forming what are sometimes spoken of as nutritive fibres.

1807. It is a matter of daily experience that the colour of the face

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quickly changes under the influence of mental impressions. Here the nerves are supposed to alter the diameter of the capillaries:—the constriction of these causing paleness, while their dilatation produces the blush of shame or anger. However correct this supposition, still we must not forget that many energetic stimuli—such as repeated electric shocks—(§ 663) effect no direct change in the capillaries. Hence this rapid alteration of their size presupposes collateral causes, such as are hitherto unknown. So that at present we are alike unable to decide,—whether, under ordinary circumstances, the nerves determine the afflux of blood to the several organs of the body,—how they do so,—or what influence they exercise on the phenomena of inflammation and exsudation.

1808. The increased lachrymal secretion which accompanies the act of weeping is generally due to nervous excitement. The sight or recollection of pleasant food causes a remarkable increase of the fluids of the mouth. Anger often gives rise to effusions of bile. When the nerves which supply the interior of the kidney are tied or cut through, a blood-red and albuminous urine is often evacuated. Sexual excesses frequently cause an increased secretion of some of the sebaceous glands of the face, especially of those which occupy the neighbourhood of the alæ nasi: together with a more copious desquamation of the epidermis of this region. And the milk of wet nurses is sometimes seriously altered by mental emotions.

1809. Since the blood-vessels and gland-ducts contain contractile tissues, we may suppose that the nerves first excite these constituents, and thus indirectly alter the porosity of the septa (§ 861) themselves. But it is obvious that this theory, though in itself probably correct, only affords a very general explanation. At present, our physical observations (§ 861) are so few, and our chemical analysis of the blood and the secretions so imperfect, that it is impossible to enter into any details. And, in addition to this, we are ignorant whether the nerves may not be capable of effecting a direct change in the corresponding mixtures of blood, secretions, and nutritional fluid—whether, in fact, they may not act like the electrolysis of a galvanic current (§ 239).

1810. Paralyzed limbs sometimes undergo a gradual emaciation. But this phenomenon also occurs without disease of the nerves, provided that the parts are made little or no use of from any cause whatever. The disuse of the muscular substance leads to its atrophy. But, on the other hand, paralyzed limbs often present a certain roundness, which is chiefly due to fat; and either appear perfectly healthy, or are at most only distinguishable by the paleness of their skin. In spite of this, however, we should be wrong to deny all visible influence of the nervous tissues in these respects.

1811. When the sciatic nerve of a rabbit or dog has been cut through,

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the animal soon runs lame on the paralyzed side. The superficial cutaneous structures over a larger or smaller space gradually become converted into a scab; beneath which an ulcer constantly eats inwards, sometimes even reaching the bone, and causing its destruction by caries. But this active degeneration occupies the very places that chiefly sustain the weight of the body in standing or walking: and may therefore be ascribed to the unusual pressure to which they are so frequently exposed. The remainder of the leg, however, preserves its former condition, with some exceptions which will shortly be mentioned. These facts are a direct proof that the inaction of the nerves destroys that capacity of resistance which belongs to the healthy tissues; so that agencies which, under normal conditions, would produce no disturbance, inflict serious injuries on the structures of the paralyzed limb.

1812. Similar appearances are also seen in the human subject. When a piece of the sciatic nerve has been excised for neuroma, the terminal portion of the affected limb gradually becomes bent like a club-foot: and those parts subjected to pressure are attacked by scabs, ulcers, and even caries. The paralyzed foot becomes extremely blue when exposed to cold, and is very liable to be affected with chilblains;—facts which prove that it has suffered just as much in its capacity of resisting the influence of temperature, as in its ability to withstand mechanical agencies. To the same cause we may obviously ascribe the similar results seen when paralyzed or dropsical persons, whose vital energy is sunken, lie upon their heels or sacrum. And electric shocks, which stimulate the nerves (§ 242), may be advantageously used as a means of cure.

1813. There are some phenomena which indicate, that these changes do not depend on the nerve-fibres that preside over voluntary movements. We have seen (§ 1731) that the larger primitive division of the trigeminal nerve (*v*, Fig. 322, p. 484) includes no fibres of this kind, and therefore does not govern the movements of the muscles of the face, but only the sensibility of its skin. Still, after section of this nerve in the rabbit, scabs often form gradually upon those parts of the lips which are pressed against other solid bodies in the prehension of food. Hence here we may conclude that these changes are produced by either sensitive or nutritive nerves.

1814. The epidermis of the foot desquamates more freely after division of the sciatic nerve. The epidermis of the hand or foot of a person affected with hemiplegia often presents a remarkable smoothness. The other horny tissues also exhibit many extraordinary changes. The nails often appear to grow more strongly and irregularly. Rabbits in whom one trigeminal nerve has been cut through, gradually lose the tactile hairs of the corresponding lateral half of the face. In dogs, the leg paralyzed by section of the sciatic nerve often becomes bald here and there. The limbs of persons who have been long paralyzed contain

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more fat than muscle. The muscular fibres themselves are generally paler. And although the contractile tissues emaciate more quickly and remarkably; still the other soft parts, and even the bones, gradually become atrophied.

1815. The appearances which follow section of a frog's sciatic nerve, vary greatly with the external circumstances. When the animal is kept in water, the paralyzed extremity frequently undergoes considerable swelling. An extraordinary quantity of fluid collects in the lymphatic spaces: *i.e.*, in those cavities which intervene between the skin and many of the muscles. While, when the frog is kept in damp moss, this change is either absent or much less marked. Hence the effusion is not so much an exsudation of liquor sanguinis, as an entry of water from without, through the paralyzed tissues of the skin. We may conjecture that its collection is chiefly due to a change in the porosity of this septum.

1816. The paralyzed limb often suffers from emaciation, ulcers of the foot and knee, mortification of some of the toes, or desquamation of the cuticle in large coherent fragments. But it is impossible to state how these phenomena are related to each other. Besides this, similar changes sometimes occur without any special injury of the nerves, where frogs are kept in a narrow receiver, or in impure water, or in other abnormal situations.

1817. Ulcers and fractures of paralyzed limbs may heal just like those of healthy ones. Hence suppuration (§ 1056), granulation (§ 1059), and the production of callus (§ 1072), are in themselves quite as independent of the nerves, as the first moulding of the several tissues in the embryo or adult animal.

1818. Hitherto nothing very constant or important has been observed in the temperature of paralyzed parts. Their cutaneous surface generally feels cool. But the thermometer shows that the temperature of the skin is lowered in some instances, and raised in others. Nor do thermo-magnetic researches present any constant deviations, from which conclusions can safely be deduced.

1819. The great influence exerted by respiration on the process of combustion, and therefore on the animal heat (§ 1177), is occasionally seen after sections of nerves also. Thus a bird whose vagi have been divided sometimes at first presents a lower heat, which is succeeded by a higher one shortly before death.

1820. The rapid decrease of cutaneous heat which is met with in sickness, nausea, or fainting, depends in the first instance on the influence of the nerves. It is probable that these cause a constriction of the capillaries of the skin, which are therefore traversed by less blood. Still the phenomenon is not completely explained by this single circumstance. And the function of respiration is not always affected in exactly

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the same proportion as the cooling of which it is the chief cause:—a fact which indicates that the nerves themselves may have a direct action of this kind:—an action such as our present knowledge of Physics will certainly not allow us even to guess at.

1821. Paralysis of the olfactory, optic, auditory, or hypoglossal nerve, does not necessarily disturb the nutrition of the corresponding sensuous organ. But the cornea and crystalline lens of the eye often become cloudy after amaurosis—*i.e.*, paralysis of the retina—of long standing. Still this degeneration does not immediately depend on the paralysis of the fibres of the optic nerve, but on the inflammatory phenomena which subsequently occur.

1822. Section of the common motor nerve of the eye, or of the fourth, sixth, or facial nerve, produces no immediate change in the nutrition of the corresponding muscular structures. These, at most, only undergo a slow emaciation, like other inactive contractile substances (§ 1810). Paralysis of the hypoglossal nerve is attended by similar phenomena: the surface of the tongue subsequently presenting wrinkles, such as are not normally met with. And since the animal is incapable of effecting direct changes in the position of its tongue, this organ is often injured by the teeth. Hence ulcers and scabs frequently appear.

1823. The trigeminal and vagus nerves, both of which include numerous sensitive fibres (§§ 1730 and 1746), give rise to different phenomena. When the fifth nerve of a rabbit is cut through within the cranial cavity, the pupil of the corresponding eye immediately diminishes in size. The blood-vessels soon become greatly distended: and the mucous secretion of the conjunctiva is increased. These changes are followed by a profuse suppuration; which somewhat resembles the Egyptian or syphilitic ophthalmia, or that of the new-born infant. The iris also then becomes distended with blood; while the conjunctival sac, the anterior chamber of the eye, and the pupil, fill with exsudations. A funnel-shaped ulcer eats into the middle of the cornea, which also becomes cloudy in the rest of its substance. From this point the destructive process may take a retrograde course. In that case, the suppuration gradually diminishes. But the opacity of the cornea remains, as do also the exsudations in the anterior chamber and pupil; so that the sight is permanently lost. Section of the fifth nerve in dogs or cats, or disease of this trunk in the human subject, often causes the eye to burst, in consequence of such suppuration and ulceration. Its softer internal parts—such as the aqueous humour, the crystalline lens, and the vitreous body—are then evacuated; and the whole is finally converted into an amorphous mass. When this storm has passed over, the suppuration gradually ceases.

1824. Many experimenters state that these disturbances in the nutrition of the eye are only produced by cutting through the trigeminal nerve at the Gasserian ganglion (*x*, Fig. 322, p. 484). They

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therefore conclude that these important changes in the constituents of the organ of sight depend upon the influence of that ganglion, or of those sympathetic fibres which may be supposed to arise from it (§ 1766). But in the albino (§ 1028) rabbit we may easily convince ourselves that, even when the injury lies between the Gasserian ganglion and the brain, and does not implicate the whole of the nervous trunk, it is quickly followed by this vascular distension. Hence there is no absolute proof that the ganglionic tissues necessarily co-operate.

1825. Where the eye has not been evacuated, an examination of the rabbit's body after death shows that only the anterior half of the globe is attacked. While the cornea is opaque, and the anterior chamber completely filled with exsudations, these but partially occupy the pupil, and at most give off a few bands to the capsule of the lens:—the substance of the lens itself, together with the vitreous body, the sclerotic, the choroid, and the retina, remaining quite free from such morbid appearances. Now since this storm of inflammation proceeds from the delicate conjunctival surface, it is possible that here again the first impulse is given by the destruction of that capacity for resistance which the tissues possess (§ 1811); and that all the subsequent phenomena are mere consequences of this primary disturbance.

1826. We have already (§ 1751) seen that the inflammation of the lungs produced by section of the vagus may be explained in two ways. Some regard it as the simple consequence of a chemical irritation, which is itself caused by a defect in the mechanism of deglutition. While others look on it as a direct effect of the nervous paralysis; such as is seen in other organs of the body, though with somewhat varying results. And recollecting that the delicate pulmonary tissues are constantly exposed to the influence of the inspired air, and that this very circumstance causes a large proportion of mankind to die of pulmonary consumption,—we might conjecture, that, here again, a paralysis of the nerves of these organs has destroyed their capacity of resistance. If the gastric juice really loses its acid character after section of the vagi (§ 1756), the fact may be attributed to a change in the porosity of the coats of the vessels, and the limitary membranes of the glands.

1827. If the external branch of the spinal accessory nerve (§ 1758) of rabbits and cats be torn out on both sides, without any further injury of the vagi, the animals may continue to live for a long time without this pulmonary degeneration. So that here also the disturbances of nutrition are produced by the sensitive, and not by the motor (§ 1813) nerve.

1828. Although the distribution of the sympathetic has led to its being regarded as the special nerve of nutrition, experiment has not hitherto succeeded in verifying any series of peculiar and unusual nutritive phenomena in connection with this part of the peripheric

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nervous system. It is true that extirpation of the superior cervical ganglion of the sympathetic is followed after some time by inflammation of the conjunctiva of the corresponding eye, attended with protrusion of the membrana nictitans, and an increased secretion of mucus or tears. But such disturbances of nutrition bear no comparison with those which follow paralysis of the trigeminal nerve (§ 1823). According to Schiff and Bernard, removal of the two superior thoracic ganglia of the rabbit is followed by increased distension of the blood-vessels of the pericardium, and the effusion of exsudations around the heart itself. We have already seen (§ 1808) that paralysis of the renal nerves is capable of changing the characters of the urine. Extirpation of the terminal segments of a frog's sympathetic trunk frequently gives rise to effusions in the abdominal cavity or viscera, and to signs of hyperæmia in the different tissues there. But the subsequent phenomena are so different in different animals, that it is at present impossible to establish any specific details. According to Guenther, division of the (mostly cerebro-spinal) nerves of the horse's penis causes the corpora cavernosa to become extremely distended with blood, while the sensibility of the corresponding integuments is almost lost.

1829. We must admit that most parts of the ganglionic system are so deeply placed, that in the living animal they cannot be reached without the infliction of considerable accompanying injuries. Hence many experiments fail, on account of the necessary operations being soon followed by death. In others, the subsequent inflammatory phenomena are mixed with the effects produced by the section of the nerves themselves. Examples of such ambiguous results may be seen in the changes which follow excision of the posterior extremity of the frog's sympathetic, or the renal nerves of the mammal. But however small the number of observations hitherto made, it is important to notice that the extirpation of a considerable portion of the sympathetic has sometimes been followed by very little disturbance of nutrition. Even the removal of the whole cervical trunk is unattended by any important change in those tissues which form the commencement of the respiratory and digestive apparatus. And the transplantation of testicles already referred to (§ 865) shows that paralysis of the corresponding nerves does not prevent the preparation of a seminal substance provided with normal spermatozoa (§ 1215). Large pieces of the Fallopian tubes may be cut away without the appearance of any other phenomena than the ordinary inflammation and exsudation attributable to the injury. It is true that the numbers of nerves which are possessed by the vessels, glands, and other organs of secretion,—as well as by various parts having little sensibility and motion,—plainly indicate the existence of certain special arrangements, such as require the aid of nervous tissues. But these refer to

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delicate relations, which are not even indicated by our existing knowledge, and which will probably long baffle all the efforts of the observer of nature.

1830. Hitherto those internal changes which accompany the action of the peripheric nerves have been chiefly investigated in the motor fibres (§ 1705). For the resulting muscular contraction has the advantage of allowing the easy and accurate performance of many delicate experiments, and exhibiting some very definite peculiarities.

1831. It has already been stated (§ 1237) that a local stimulus, which impinges upon a point *e* (Fig. 351) of the sciatic nerve *a b* of a prepared frog (§ 1237), throws the gastrocnemius *c* into contraction. A certain molecular change is propagated from *e* to the extremities of the nerve present in *c*. It finally induces that change in the physical properties of the muscular substance which we designate contraction. But contraction may be produced by any local irritation of the nerve — whether mechanical, thermical, electrical, or chemical. The nervous medulla must therefore possess a peculiar capacity for communicating the corresponding change of any special point, from one of its parts to another, to the very end of its course.

FIG. 351.

1832. When the sciatic nerve is cut through, tied, or otherwise seriously injured in the point *d*, no stimulation of *e* can cause *c* to contract. However accurately the cut surfaces at *d* may be apposed to each other, *e* still retains this disadvantage. Hence the propagation of the physical change in the nervous medulla presupposes that its molecules possess their natural situation and properties.

1833. This fact at once explains the ordinary distinct conduction of the nerve-fibres (§ 1710). However closely these lie to each other in a branch of nerve (Tab. V. Figs. 68, 69), still their medulla is isolated by means of the neurilemma in which it is enclosed. The change excited at a definite point (*e*) of the fibre may be propagated in all directions: — *i.e.*, both in its length and breadth. The filamentous form of the primitive fibre is the reason why the first of these directions predominates. And since the molecules of the medulla of two neighbouring fibres are not in contact with each other, all communication is rendered impossible. The rare exceptions to this rule will hereafter receive a special consideration.

1834. It has frequently been conjectured that the nervous principle or agent—*i.e.*, the force upon which the action of the nerves depends —is nothing more or less than electricity. But the fact adduced in

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§ 1831 will at least prove that it is no ordinary progressive movement of a galvanic current with which we are here concerned. For since this would be able to break through the moist animal tissues in contact with each other, we could scarcely imagine an isolated conduction on the part of the fibres (§ 1710). And supposing that the irritation acting upon *e* led to a disturbance of electric counterpoise—a disturbance which was carried onwards through *e d b*, as through a conducting wire,—we might expect that the division at *d* previously mentioned would not oppose any insurmountable obstacle to the mechanical stimulation of *e*.

1835. Electrical phenomena form the most delicate means of testing this view with which we are at present acquainted. The galvanometer (§ 220) betrays molecular changes such as the eye cannot recognize under the highest magnifying powers. The use of the electric current points out states which are inappreciable by all other means of experiment. And, at the same time, the galvanic stimulus is better adapted than any other to exhibit those alternate electrical changes which obtain in the more remote parts of the nerves.

Fig. 352.

1836. Let us suppose *a d*, Fig. 352, to be a moistened linen thread, a wet cotton-wick, or a fresh leaf- or flower-stalk. If *a* and *b* be connected with the two poles of a galvanometer (*x* and *u*, Fig. 43, p. 76), and *c* and *d* with those of a galvanic circuit (*u* and *s*, Fig. 52, p. 81), the current will take the shortest route through *c d*, without the occurrence of any change in *a b*. Hence the galvanometer will remain at rest during the passage of the electric current through *c d*. But the fresh nerves lead to very different results.

Let us imagine that *a*, Fig. 352, is the central end of the nerve, corresponding to the brain or spinal cord, while *d* is its peripheric extremity—here the central current passes from *d* to *a*, and the peripheral from *a* to *d* (§ 228). On connecting the two poles of the galvanometer with *a* and *b*, the magnetic needle presents a deviation, which is due to the chemical difference of the two points of contact, to the original nervous current (§ 225), or to both of these conditions together. Hence it may be central or peripheral, according to collateral circumstances. If we wait until the needle rests, and then connect *c* and *d* with the poles of the galvanic circuit, it undergoes a new deviation. And the kind of deviation always indicates that the current produced in *a b* has the same course as that in *c d*. If the galvanometer previously showed only the nervous current, this deviation is increased when the exciting current proceeds in a corresponding direction. In the opposite case, it will be diminished, or altogether overcome. In all these experiments, it is at the first instant that the magnetic needle vibrates most energetically. It afterwards gradually

recedes, but is finally arrested at a point which always indicates the direction of the exciting current. When the circuit is broken, the needle swings vigorously backwards, and subsequently rests in some other place.

1837. The electric current which excites *c d* throws the remaining molecules of the nervous medulla into a state of tension or polarity (§ 240) corresponding with its own. We must therefore substitute the diagram, Fig. 353, for that representation of the electric properties of the nervous molecules which was given in Fig. 47, p. 79. This continuous displacement of the smallest particles reminds one to some extent of the permanent rotation of the planes of polarization which is produced by powerful inductive currents (§ 256). Hence Du Bois, who first investigated this phenomenon, named it the electrotonic condition of the nerve-fibres.

FIG. 353.

1838. The other tissues of the frog either exhibit no electrotonic state at all, or one which is much weaker than that of the nerves. It is true that strips of muscle also give rise to positive results. But, other circumstances being equal, these are much weaker. And we are entitled to doubt whether such results depend on the muscular fibres, or on the nerve-fibres which run between them. The fact that other tissues provided with nerves are inferior to the muscles in this respect, would rather decide the question in favour of the muscular substance itself.

1839. The electrotonic condition of the nerves is an immediate consequence of a property already assigned to (§ 1831) the nervous medulla: viz., that of propagating change from molecule to molecule. Hence this propagation is destroyed by section, deligation, and local injury, whether thermic or chemical. Under such circumstances the columnar polarization (Fig. 353) struggles, as it were, with the original peripolar arrangement (Fig. 47, p. 79, and § 223).

1840. When the exciting current takes the longitudinal direction (*a d*, Fig. 352), the conditions are more favourable than when it passes transversely through the nerve. The movement of the magnetic needle is also favoured by an increased length of the irritated tract (*c d*), and by an approximation of the conducting segment (*a b*) to the part (*c d*) traversed by the galvanic current. Hence the electrotonic effect diminishes with the distance from the seat of irritation:—a circumstance which shows that there is a certain resistance to the propagation of the molecular change from one atom of the nervous medulla to another. We shall hereafter find something similar to this in the vital actions of the nerves.

1841. The more delicate properties of the nerves sometimes exercise an extraordinary influence on the results. Other circumstances being

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equal, the pale white nerves of feeble and ill-nourished frogs give a smaller deviation of the magnetic needle. Indeed, with a weak circuit, or unfavourable collateral conditions, the experiment sometimes fails. If the phenomena be investigated day after day in the dead frog, the capacity of falling into the electrotonic states will be found to last longer than that of contraction. Thus it may be present in the putrefying animal. But at a certain stage in the decomposition of the nervous medulla, it is permanently lost.

1842. These facts suffice to show, that the electrotonic action of the nerves does not quite coincide with that process on which the excitement of sensation or motion depends. And the circumstance that it continues even during the closure of a galvanic current, affords another distinction, which completely separates the two classes of phenomena (§ 233) from each other.

1843. That columnar polarization of distant portions of nerve which is produced by the electrotonic state, as well as the changes of electric condition by which it begins and ends (§ 233), may also be observed in some physiological experiments. It is to these circumstances that Du Bois attributes the secondary contraction (§ 1287) which proceeds from the nerves; as well as that which he has named the paradoxical contraction.

1844. We have seen (§ 1287) that a second prepared frog, the nerve of which lies upon the muscles of the first, begins to contract, when these are thrown into contraction by the (preferably galvanic) irritation of their own nerves. But the exciting prepared frog or its muscles may be replaced by a piece of nerve. The nerve of the second prepared frog is laid on the longitudinal and transverse section of the piece of nerve, or on the first of these only; and a certain extent of the latter nerve, at a distance from the point of contact, is connected with a strong galvanic battery. The occurrence or cessation of the electrotonic state leads to a secondary contraction of the prepared frog. When the place excited is too far from the contracting part, the experiment sometimes fails (§ 1840).

1845. The paradoxical contraction is a collateral effect of what is essentially the same phenomenon. When a motor or mixed nerve, B, (Fig. 354), is stimulated at *i k* or any other part of its course—whether mechanically, thermically, chemically, or by a weak galvanic current—we only get contractions of those muscles which are supplied by B in its further and peripheric distribution, or which lie beyond *e f* (§ 1712). But when, on the other hand, a certain length of B is exposed to the influence of a strong galvanic circuit, so that *n* falls into the electrotonic state, all the muscles which are governed by A (and hence those also which obey the trunk C), contract energetically. This result immediately depends on the fact, that the elec-

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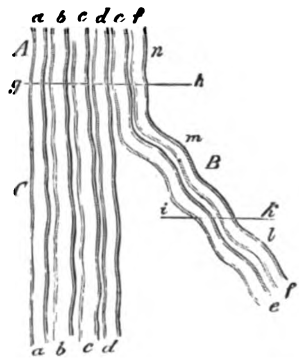
trotonic condition advances, not only in the direction of the living conduction of the primitive fibres—*i.e.*, centripetally in the sensitive, and centrifugally in the motor, fibres (§ 1707)—but also in the opposite course (§ 1836). The columnar polarization which attacks *n*, then secondarily excites *a b c d*. Here again, the nearer the excited portion, the greater the likelihood of success. And it is evident that such paradoxical contractions, produced by powerful electric currents, will be capable of frustrating the chief experiment which proves the law of Bell (§ 1720). Hence, for this purpose, galvanic stimuli should be used.

FIG. 354.



1846. It has already been stated (§ 226) that the electro-motor properties of the molecules of a fresh nerve resemble those of the muscular fibre. Hence its longitudinal surface is positive with respect to its transverse section. But just as muscular contraction is accompanied by a negative deviation of the current (§ 1286), so, according to Du Bois something similar occurs during the action of nerves.

1847. Here again electrical irritation affords more favourable results than any other stimulus. An inductive apparatus which is capable of tetanizing—*i.e.*, of continuously exciting—the piece of nerve, and a delicate galvanometer of the ordinary construction, will, when properly arranged, suffice to prove this negative deviation of the current. But when other irritants are employed, the galvanometers at present made use of fail to show this momentary decrease of the nervous current. Hence Du Bois made use of a very sensitive instrument, which possessed 24160 coils (§ 220), and underwent a violent deflection on applying the muscular or nervous current. A frog was poisoned with strychnine, and its sciatic nerve disconnected from the muscles. On uniting the longitudinal and transverse sections of the nerve with this galvanometer, the magnetic needle sometimes receded from 1° to 4°, at the time when the action of the poison would have produced tetanic spasms in the muscles of an uninjured animal. When, under similar circumstances, the nerve is severed from the spinal cord, the deviation does not occur. Repeated mechanical or thermical irritations are also capable of producing a negative deviation of from 1° to 3°: but chemical stimuli exercise a less marked influence. And gradually scalding the skin of the leg and foot may finally oblige the sciatic nerve to indicate, by the galvanometer, the change which is going on in its own interior.

1848. On testing the nerve by electricity, the amount of negative

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deviation will be found to increase with the change of electrical tension (§ 231), and with the length and proximity of the stimulated portion. Although the same conditions are requisite for the electrotonic state (§ 1836), still they do not hold equally good for both phenomena. The negative deviation is much less dependent on the distance of the excited and conductive portions, than is the columnar polarization of the nerve. But both are essentially determined by the character of the nerve (§ 1841), both are suspended by tying or cutting it across (§ 1847), and both are raised again by its recovery (§ 1284). And in both, that transmission of the exciting current which corresponds to the transverse axis of the nerve is the condition least favourable to the negative movement of the magnetic needle of the galvanometer.

1849. According to this, the negative deviation of the nervous current accompanies that internal change which is undergone by the nerves of sensation or motion at the instant of their action. But in the centripetal and centrifugal nerve-fibres (§ 1707), it may be detected proceeding in two directions:—in the former, towards the periphery also; and in the latter, towards the centre (§ 1805). Hence the change of molecular condition extends on both sides. Still we shall hereafter see that, in spite of this, certain one-sided contractions result. It may therefore be questioned whether the negative deviation has a definite energy in this respect, or whether its strength is only a subordinate and collateral effect of deeper changes in the nervous medulla.

1850. According to Du Bois, the galvanometer is capable of indicating many of the changes which the nervous substance undergoes in consequence of putrefaction (§ 1693). When the longitudinal and transverse surfaces of the nerve are connected with the poles of the galvanometer, the electric opposition diminishes, as soon as the exposed transverse surface begins to undergo decomposition. By making a new transverse section, we restore the previous results. And the infliction of severe injury upon even a limited spot, sometimes inverts the direction of the current in the nerve, just as in the smaller muscles. The electromotor properties last very little longer than the capacity of exciting contraction. When they are quite absent, the nervous substance is found to be coagulated (§ 1693). They never return.

1851. We have already (§ 1241) seen that electric currents constitute the most delicate test which can be applied in the living body, or the prepared frog. There is probably no substance so sensitive to electrolysis (§ 239), and to the other effects of weak stimuli of this kind, as that unstable compound which forms the contents of the nerves (§ 1693). The results obtained by such experiments acquaint us indirectly with many internal molecular relations, which would otherwise escape our notice.

1852. The contractions produced by galvanic irritation of the nerves

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may occur at four different times:—at the instant of closing the circuit, during its closure, at the moment of opening it, and after it has been opened. Since a verbal description of the numerous differences here met with would be both prolix and confusing, it will be better to make use of a simple and summary language,—such as at once shows, both the direction of the electric current, and whether it produces an instantaneous contraction only, or a series of alternating spasms.

The strength of the contraction occurring in a given experiment is expressed by advancing letters or numbers: which also show what muscular regions of the preparation have contracted. *A*, *B*, *C*, *D*, and *E*, indicate that the muscles of the thigh and leg (or the whole hind leg) of a frog have contracted,—*A* representing the smallest, and *E* the greatest, degree of contraction:—while *a b c d e* indicate that only those of the thigh are affected. The figures 1, 2, 3, 4, 5, represent the same ascending succession for that ordinary action of the galvanic prepared frog in which the muscles of the calf (*c*, Fig. 351, p. 541) take the most important part. The letters *z z*, or *z*, indicate a series of alternate convulsions lasting some time: while the cipher, 0, means that no change whatever is observed in the muscular substance. The letter *p* is the peripheric, and *c* the central, current,—*i.e.*, in the first case, the positive galvanic current goes from the nervous centre towards the muscular or sensuous organs; while in the latter, it takes the reverse course.

Every formula of this kind includes four values. The first corresponds to the event which occurs at the instant of completing the circuit; the second to that on breaking it; the third to that during its completion; the fourth to that during its interruption. It will be seen that the value which appears on breaking the circuit is put before that present during its closure. This somewhat artificial arrangement has been adopted because, in most experiments, it is chiefly the closing and opening contractions (§ 1241) which we have to consider; these being often inversely proportionate to each other. The two phenomena are therefore brought together, in order that their difference may be more easily perceived.

For example, the formula $p = 3.\ 0.\ 0.\ 0.$ and $c = 0.\ 3.\ 0.\ 0.$ means that a galvanic prepared frog contracted at the instant of closing the peripheric current, and at that of opening the central one; but at no other time.

1853. We will first examine the phenomena in the living animal which has not sustained any important injuries. The frog is properly tied upon a board, and a metallic conducting needle is stuck into the course of the sciatic nerve shortly after its emergence from the cavity of the belly (below *b*, Fig. 334), while a second is inserted into it immediately below the knee-joint. When these two needles are suitably connected with a galvanic circuit (Fig. 52, p. 81), the electric current traverses almost all the femoral portion of the sciatic nerve. On selecting a very

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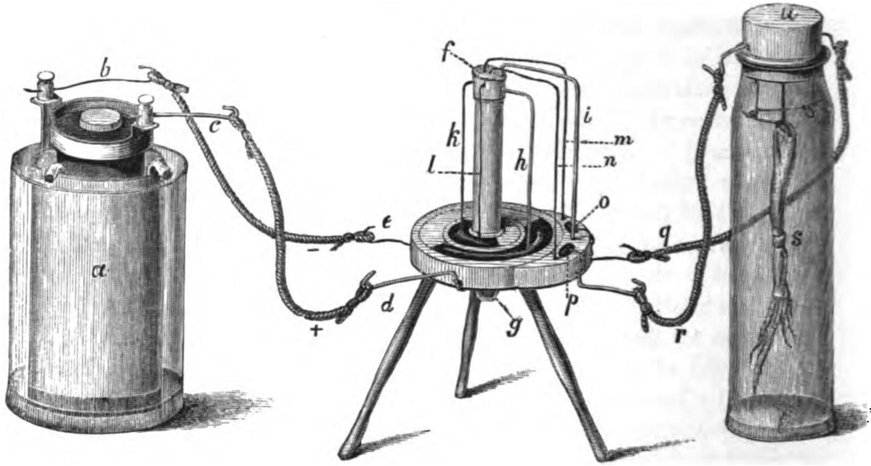
weak galvanic stimulus, the direction of the current exercises no appreciable influence upon the final result. Whether the positive current

FIG. 355.



runs peripherally or centrally (§ 228), we only get a contraction at the instant of closing the circuit. Hence the formula of the law of contraction which appears under these simple circumstances will be $p=c=A$ to E. 0. 0. 0.

1854. We may examine the animal from time to time during a whole day or more, without finding any essential change in the result just mentioned. Setting aside some exceptions which will presently be mentioned, this law of contraction of the living nerve holds good after narcotization with ether or chloroform, poisoning with strychnine or opium, decapitation, and division of the sciatic plexus (*a b c d*, Fig. 334, p. 507) or nerve in the living or dead animal. Finally, under all these circumstances, it may remain unaffected as long as any sensibility lasts. And by inserting the conducting needles into the facial nerve of a dog or rabbit (§ 1735), we may convince ourselves that the same law of contraction holds good in mammalia also.

1855. When the sciatic plexus or nerve of a recently beheaded frog has been pressed, pinched, or otherwise injured, a contraction—usually a weak one—is often added at the instant of breaking the circuit. Hence we generally have $p=c=A$ to E. C. 0. 0. instead of $p=c=A$ to E. 0. 0. 0. But on repeating the experiment some time afterwards, the simpler law of contraction often appears. Hence this injury produces a certain change in the nervous substance,—a change which extends beyond the place immediately attacked, and lasts for some time, but is subsequently lost. Diseased and emaciated frogs often exhibit these double actions spontaneously.

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1856. A frog which has long exhibited the ordinary law of contraction, offers closing and opening contractions ($p=c=A$ to E. A to E. 0. 0.) as soon as the weak galvanic current is replaced by a stronger one. If the latter has but a moderate strength, so as only to produce a change from zero to a moderate degree of tension (§ 232), the simpler law of contraction may often be produced by gradually bringing the conducting needles closer to each other, so as to transmit the current through a constantly diminished segment of the nerve. Hence the length of the irritated tract of nerve, and the change of tension at the instant of closing or opening, are, as it were, complementary to each other.

1857. When the circuit is so powerful as to induce stronger electrolytic actions, alternate convulsions are added, especially during the closed state of the circuit. For example, in many cases we have $p=c=C$. C. zzb. 0. Previous injury of the nervous structures now and then produces the same results, even when weaker circuits are used.

1858. In decapitated frogs we frequently find that it is only a certain direction of current which produces double actions. For example, we get $p=B$. 0. 0. 0., and $c=B$. B. 0. 0. Here we may already detect those molecular states or dispositions which we shall shortly find so evident in the prepared frog. Subsequently they often disappear.

1859. In exposing a galvanic prepared frog (§ 1237) to these tests, it (*s*, Fig. 355) is placed in a glass, the bottom of which is covered with water (*t*). In this way we avoid that drying of the sciatic nerve, which is so prejudicial to the experiment. The whole is hung upon a hook of horn, and the sciatic nerve (with the plexus, *a b c d*, Fig. 334, p. 507, when it is itself too short) is slung upon two metallic wires, which pass through the stopper (*u*). These are connected with an apparatus for shifting the current (*f*), which in its turn is united to the galvanic circuit. By means of this, we can instantly exchange a peripheric for a central current, or can make currents of similar direction immediately follow each other.

1860. If a galvanic frog be prepared with the greatest care to avoid all injury of its sciatic nerve, we may often convince ourselves, by repeated experiments, that the law of contraction of the living nerve still continues. Very weak currents, or very short tracts of nerve, afford closing contractions; while at all the other periods there is no result whatever. But ordinary prepared frogs give rise to different results, since the violence done to the nerve during their preparation produces a continuous abnormal disposition,—a permanent change in their molecular state.

1861. On exposing a long tract of the sciatic nerve of a freshly prepared frog to the influence of moderate galvanic currents, we generally get double actions (§ 1855) with each of the two directions of current ($p=c=1$ to 5. 1 to 5. 0. 0). But this result appears to depend solely

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on the amount of stimulus made use of. If this be weakened, or if we make use of a very short transit of nerve, and of very weak electric currents (§ 234), we instantly get one-sided results, which vary with the path of the current, and indicate the nature of that permanent artificial disposition just mentioned (§ 1860).

1862. Here we find two chief cases. The peripheric current leads to a closing, and the central to an opening, contraction ($p=1$ to 5. 0. 0. 0., and $c=0$. 1 to 5. 0. 0.). Since the voluntary contraction of the muscles depends upon a peripheric propagation of the stimulus in the interior of the motor nerve, we have here a one-sided effect, which is uniform or *homogeneous* with the vital action. This is designated the law of Marianini. In other cases the contrary—*i.e.*, a one-sided and dissimilar or *heterogeneous* action—may obtain. The central current then furnishes a closing, and the peripheric an opening, contraction ($p=0$. 1 to 5. 0. 0., and $c=1$ to 5. 0. 0. 0.).

1863. It is easy to see that the increase of quantity which leads to the double actions, only conceals the disposition really present. But the latter sometimes so far betrays itself, that one of the two contractions is stronger than the other.

1864. In the nerves of the dead animal, the degree of susceptibility gradually diminishes. This explains why a prepared frog which at first gives a double response, afterwards only affords a single one to the same stimulus. We may confirm it by preparing one thigh of a frog immediately after death, and the other some hours subsequently.

1865. At the period of recovery, similar phenomena also obtain in the uninjured animal (§ 1853), or in the prepared frog which exhibits no artificial disposition. Here a previous injury often gives rise to double actions, with weak currents and moderate lengths of nerve. While rest reproduces that one-sided action which is the law of contraction for the living muscle (§ 1848).

1866. It has been conjectured that the one-sided and heterogeneous action precedes the homogeneous one, since it more closely corresponds to the circumstances which obtain during life. According to such a view, a perfectly vigorous prepared frog would at first give $c=1$ to 5. 0. 0. 0., $p=0$. 1 to 5. 0. 0.; and $p=1$ to 5. 0. 0. 0., $c=0$. 1 to 5. 0. 0. subsequently. But experiment by no means confirms this supposition. We may convince ourselves that the homogeneous or heterogenous disposition is originally present. Besides, the law of contraction of the living nerve differs just as much from one as from the other.

1867. At present it is impossible to say why one preparation furnishes a homogeneous, and another a heterogeneous, one-sided current.*

* On this subject the reader may refer to some more recent observations by Prof. Valentin in Vierordt's "Archiv fuer Physiologische Heilkunde," vol. xii. p. 66. Their novelty and importance induce me to sum up their chief results.

The exceptional instances of heterogeneous one-sided contraction generally occur under

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Violent compression, or any other great injury of the nerve, always causes such an essential and permanent change in its medulla, that it returns different answers to the two directions of current. The homogeneous and one-sided action, which corresponds to the law of Marianini, then occurs much more frequently than the heterogeneous one. But the particular result does not depend on any original arrangement or property of the medulla during life. For it may happen that one thigh of the same frog gives rise to homogeneous, and the other to heterogeneous, results. In rare instances, the disposition of the same nerve may even become inverted in the course of the experiment, as a consequence of the

collateral circumstances of two kinds:—(a) the lapse of a considerable time after death; and (b) much injury of the nerve in preparation, especially of its length. But we cannot intentionally produce these conditions, so as to invert the current at will. By means of changes of temperature, such an inversion can, however, be effected.

A heat of 105° to 115° annihilates every trace of susceptibility to contraction: not only in those instances in which it suddenly changes the preparation into a pale, stiff, brittle mass, but also when (this physical change having been avoided by the slow induction of a nearly equal heat) the mass retains its capacity of subsequently falling into the state of *rigor mortis*.

A moderate increase or decrease of the ordinary temperature respectively increases or decreases the force and frequency of the contractions.

The degree of cold required to destroy the susceptibility is very considerable. At 14°, the preparation remains active.

In varying the temperature of the surrounding air, we come to a degree of heat and of cold, which renders the nerves incapable of excitement by a strong simple circuit, but leaves them still amenable to the influence of the electro-magnetic apparatus. The restoration of the previous temperature completely restores the latent susceptibility.

On exposing the frog's heart to similar temperatures, all of these variations are repeated without the aid of electricity.

But the most peculiar effect of cold is its reversing the ordinary disposition of the nerves.

When a prepared frog, whose motor nerve follows the law of Marianini, is enclosed in a receiver surrounded with snow or ice, and cooled to a certain degree, it gives the one-sided heterogeneous result—viz., a closing contraction for the central current, and an opening for the peripheric one. On applying a further degree of cold, these become latent. But they return after its removal by warming. And continuous warming destroys the reversal, and restores the original disposition: so that the peripheric current has only closing, and the central, opening, contractions.

The result depends upon the altered temperature of the nerve, and not of the muscles. This is shown by an apparatus in which the latter are excluded from its influence. But since the slow and feeble contractions already alluded to are not produced, the latter probably depend upon the muscular substance itself.

This reversal, latency, and recurrence, all occur earlier in a central segment of nerve than in a peripheric one. Indeed the disposition may be reversed in a central portion of the nerve, at the very time that a lower or peripheric tract is still exhibiting the ordinary condition. While when the current is passed through both nerve and muscle, the results become very variable and uncertain.

It would seem that, although higher temperatures render latent the susceptibility for the simple circuit, they do not reverse the disposition like cooling.

When the disposition is originally reversed at the ordinary temperature, neither heat nor cold will invert it. It would therefore follow that the one-sided heterogeneous action is incapable of being affected by changes of temperature; while the ordinary homogeneous action can only be reversed by cold, and not by heat.

At ordinary moderate temperatures, the one-sided results occur later in the sciatic nerves of the prepared frog which lies *in situ*, and is bathed by nutritional fluid, than in the isolated nerve. The same difference is repeated in the influence of cooling.

The temperature at which the reversal takes place varies according to the state of the animal: preparations from animals ill-nourished, or some time dead, undergo the change at a higher temperature, or, in other words, with a smaller degree of cooling. This confirms the view which regards the heterogeneous disposition as unlike the vital state of the nerves, and as implying a lower degree of activity than the homogeneous action.—EDITOR.

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influences exerted by external circumstances. But, as a rule, the disposition once taken remains until the last relics of susceptibility disappear.

1868. We might easily conjecture, that the various dispositions which cause the law of contraction for living nerve, and the artificial one-sided action of the prepared frog, are accompanied by differences in the electrical relations of the nervous medulla. But since Du Bois has frequently examined living and dead nerves, which certainly differ greatly in this respect, we may rather suppose that the difference is not so much in the chief phenomena themselves, as in the several circumstances which determine their amounts.

1869. It has already been remarked (§ 1862) that the contractions are generally absent during the closure of weak circuits;—*i.e.*, during the transit of currents of pretty uniform tension, and but moderate electrolytic powers. Still experience shows that the actions these evoke are not the less definite. The weak electrolysis leads to permanent changes of disposition, which gradually disappear as the preparation recovers.

1870. Supposing that we have an ordinary prepared frog, which gives a homogeneous one-sided current ($p = 1$ to 5. 0. 0. 0., and $c = 0.$ 1 to 5. 0. 0.), and that we allow a peripheric electric current to pass continually through it, we may carry this so far that no closing contraction occurs on introducing a new peripheric current,—the latter remaining without any action whatever (p=0. 0. 0. 0., c=0. 1 to 5. 0. 0.). On allowing a central current then to traverse the same length of nerve for some time, the closing contraction returns when the peripheric current is subsequently introduced (p=1 to 5. 0. 0. 0., c=0. 1 to 5. 0. 0.). This alternate phenomenon is generally called the *Voltaic alternative.*

1871. The facts formerly (§ 233) mentioned indicate that the motor nerve only produces muscular contractions when its molecular state undergoes a sudden and energetic change. We therefore get a contraction of closure or opening, when the tension of the transmitted electricity rises from zero to a given height, or sinks from the latter to the former. The same result is produced by a sudden increase or decrease in the tension of any continuous stream of electricity by which it may be traversed. But, on the other hand, those slighter differences which appear during the closure of moderately strong circuits very rarely disquiet the muscles of the ordinary prepared frog. In spite of this, however, they will, to a certain extent, electrolyze and polarize (§ 239 *et seq.*) the excited tract of nerve; and will exercise an electrotonic influence beyond it (§ 1836). Meanwhile, the nervous molecules undergo a gradual change as regards the peripheric current. On inducing a new peripheric current, no great change of the molecular state can

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occur. Hence, for the time, all susceptibility for a current in this direction is lost. But when a central current is introduced, it immediately seeks to coerce the atoms in its own direction. And after it has partially or completely destroyed the previous disposition, the peripheric current becomes again capable of producing a contraction of closure.

1872. Since the homogeneous one-sided effect is more frequent than the heterogeneous (§ 1867), the special injurious influence exercised by the peripheral current on the contraction of closure is of course very marked. Hence it has been supposed that this current is capable of weakening the nervous action, while the central current can strengthen it. But experience shows that this conjecture has only arisen from the deceptive appearances generally present. If we take one of those rare preparations which offer heterogeneous one-sided results — and the closing contraction of which is therefore observed under the influence of the central current (c=2. 0. 0. 0., p=0. 3. 0. 0.),—we shall find that this contraction can be overcome by the continuous action of a central current, while that at the opening of the peripheric current still remains (c = 0. 0. 0. 0., p = 0. 2. 0. 0.). Hence the explanation given in § 1871 affords a more accurate theory,— presuming that the two opposite dispositions really proceed from differences in the molecular arrangements or properties of the nervous medulla.

1873. The voltaic alternative (§ 1870) destroys the closing contraction more easily than the opening; both with the peripheric and central current. The opposite direction of current, which precedes the latter contraction, suffices to favour the occurrence of the positive results.

1874. Preparations the susceptibility of which has fallen very low may be so greatly depressed by continuous weak currents, as to present no contraction at all under the influence of a current in either direction. When allowed to rest some time, their capacity for contraction often returns spontaneously.

1875. The use of continuous currents plainly shows how greatly that injury of the nerve which produces the artificial disposition in the prepared frog diminishes its capacity of resistance. That is to say, the nervous medulla is much more easily and seriously injured by continuous electric currents in the prepared frog than in the living animal, For under such circumstances, the latter only exhibits double actions, instead of the simple law of contraction of the living nerve (§ 1855). Besides this, these double actions pass off more quickly than the remarkable disposition forced upon the prepared frog (§ 1871).

1876. After the disposition of the excised sciatic nerve has been altered (§ 1871) by a current of definite direction, the opposite current finds — so to speak — a more fruitful soil for its action. So that the relations of the nervous molecules become, as it were, confused. A

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rapid change then leads to contractions at times which, without these preliminaries, would afford no such results.

We will suppose that a galvanic prepared frog originally gave $p=2.\ 0.\ 0.\ 0.$, $c = 0.\ 3.\ 0.\ 0.$ An instantaneous change of the directions of the galvanic stimulus by means of the proper apparatus (§ 1859), affords $p=2.\ 0.\ 0.\ 0.$, and $c=1.\ 3.\ 0.\ 0.$ Indeed, we may remark that a current which itself presents no contractions is capable of effecting that confusion of molecular relations which is necessary to their occurrence. For example, by rapid changes of direction, we get $c = 0.\ 4.\ 0.\ 0.$, $p=0.\ 0.\ 0.\ 0.$, $c=1.\ 4.\ 0.\ 0.$

1877. We have already seen (§ 1875) that the living nerve is more independent of external influences than the sciatic nerve of the prepared frog. The dependence of both, and the energetic mobility of the atoms of their nervous medulla, sometimes increases with the number of stimulations at the beginning of the experiment. The injuries to which the sciatic nerve is exposed frequently lead to such violent deviations, that contractions appear during the state of closure, or after the opening of the circuit:—that is, during times which are otherwise periods of repose (§ 1853).

1878. A careful examination of these phenomena indicates that there are two kinds of change which may occur in the nervous medulla, so as to cause the continuance of the contractions. We frequently get preparations which exhibit alternating convulsions during the closure of the peripheral current, but not during that of the central. In other cases, it may happen that these, which have previously appeared spontaneously, cease during the transmission of a definite direction of current, and recommence on opening the circuit. Hence we have one kind of disturbance of the nervous medulla, which is supported by central electric currents, and weakened or removed by peripheral ones; and another, which is exactly the reverse of this.

1879. When a portion of nerve, *d b*, which lies near the muscles, *c* (Fig. 356), is exposed to a galvanic irritation, the results are generally more successful than when a remote segment, *a e* or *e d*, is exposed to the same stimulus. We may further convince ourselves that a longer piece of nerve (even though it be somewhat nearer the centre), affords better results than a shorter one. Both of these laws, however, are subject to some exceptions.

1880. When a continuous and moderate current is transmitted through a more central piece *a e*, while a nearer one *d b* is tested with alternate currents, the actions of *d b* do not essentially differ from those ordinarily seen. The weak electrotonic state (§ 1836) of *d b* does not noticeably alter the results. But if we reverse the experiment—*i.e.*, if we transmit the continuous current through the lower piece *d b*, while we expose the upper portion *a e* to the alternating currents—

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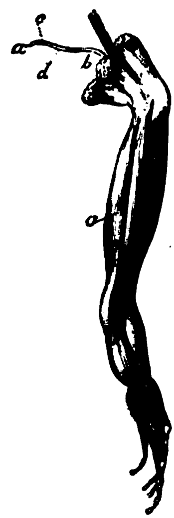
we obtain what are at most very weak contractions. These generally cease as soon as the continuous closure has lasted for a certain time. When this is interrupted, *c* contracts at the instant that *a e* or *e d* are attacked. Here the continuous galvanism of the inferior portion produces an electrotonic state, a comparatively vigorous tension of its molecules. This is not suspended by the upper current, the action of which is connected with a certain resistance to conduction. But the removal of the obstacle at once allows the upper current its free action.

FIG. 356.



1881. Here again the nerve of the living animal possesses a greater independence than that of the ordinarily prepared frog; in which the fibres are, as it were, artificially thrown out of tune. When a continuous and moderate current is transmitted through the inferior segment of the sciatic nerve, interference with its upper portion gives rise to actions which evidently correspond with the law of contraction of the living nerve (§ 1853).

1882. The sensitive fibres give rise, on the whole, to less decided results than the motor nerves. With strong galvanic circuits it becomes evident that the pain on closing the circuit is greater than the shock on opening it. This, again, is a counterpart to the law of contraction of the living nerve. Here also an unpleasant impression often continues during the closure of the circuit,—whether due to the perception of the electrotonic state (§ 1836); or to a continual alternation of closure and opening, produced by the perpetual slight vibrations of the body (§ 1193). The inductive apparatus produces violent pain on opening the circuit. But on testing the sciatic nerve of a living frog by sticking in conducting needles (§ 1853), the animal frequently shrieks with pain both on closing and opening the circuit. According to some observers, the colours of the galvanic luminous image (§ 1578) are inverted in the latter case. The organs of smell and hearing respond to the electric currents either ambiguously or not at all (§§ 1608, 1629).

1883. From all this together there can be no doubt, that the function of the nerves essentially depends on the molecular state of the nervous substance, and that this is greatly altered at the instant of their action. Hence the nervous principle works by means of material changes. And the nervous medulla possesses a mobility in this respect, such as has hitherto been found in no other substance. In this mobility, each molecule influences its neighbour by direct contact:—the loss of living force caused by this communication from point to

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point constituting the physiological resistance to conduction. And any interruption to the natural direct contact at once destroys the contactive propagation which depends upon it.

The extraordinary mobility or susceptibility of the nervous molecules allows any local disturbance that lasts a certain time — whether mechanical, thermical, or chemical—to diffuse its influence along the whole course of the nerve-fibre (§ 1831). But no stimulus alters the molecular state of the nervous medulla so easily and quickly as that of electricity. This proposition is evidently confirmed by the electrotonic state (§ 1836), by the negative deviation (§ 1846), and by the influence of the continuous transmission of galvanic currents (§ 1870). Here the most delicate electrolytic influences suffice to produce rotations of differently polarized molecules, or special phenomena of polarization.

The molecules of the living nerve are far more elastic, and therefore more independent, than those of the dead body or the prepared frog—the latter of which are coerced into a permanent artificial disposition by the previous injury. Here we have certain changes of molecular state, which betray themselves, not by direct muscular movements, but by an alteration of disposition. The recovery from this consists in the restoration of a better molecular arrangement. It does not imply the continuance of the circulation. The first repetition of the stimuli can confuse the relations of the molecules, and visibly increase their mobility.

Putrefaction destroys, first the vital actions, then the capacities for the electrotonic state and the negative deviation, and, finally, the nervous current itself. This may at last be inverted, just like the muscular current. The finer relations of the nerves and the muscular substance have what is in many respects an extraordinary resemblance to each other.

1884. The electric fishes — viz., the torpedo and the gymnotus — (Fig. 357), show that the nervous function is capable of generating

FIG. 357.

shocks of electricity. This remarkable action, which is effected by special electrical organs, will probably hereafter afford important disclosures respecting the more recondite processes of innervation.

1885. The electrical organs of the torpedo are symmetrically repeated on both sides of its body. At *a*, Fig. 358, is shown the posterior

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surface of the left organ; together with numerous large nerves, *d e f g*, which enter its interior from the trigeminal and vagus trunks. On examining its dorsal or abdominal surface, or any sections parallel with them, we see a number of polygonal structures (Fig. 359),

FIG. 358.

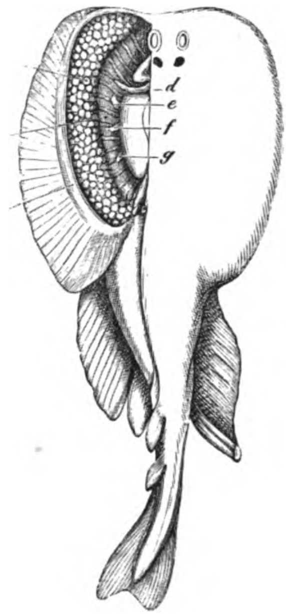
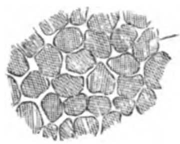


FIG. 359.



which are separated from each other by partitions of areolar tissue. While an inspection of the lateral surface, or its transverse section, presents appearances similar to those represented in Fig. 360. There are a great number of columns, which stand closely to each other, and contain transverse laminæ, separated by small intervals filled with fluid. This arrangement has a very suggestive resemblance to galvanic columns (Fig. 51, p. 80) isolated from each other by rods or walls of glass.

1886. The hundreds of columns and thousands of laminæ which occur in the two electrical organs of the torpedo, make up a large total surface; the whole of which is in contact with the fluid that occupies the intervals of the laminæ. In the electrical eel, whose electric organs are similarly constructed, and form the great bulk of the animal, the total surface is much larger, amounting to many square yards. But while the columns of the torpedo run from the back towards the belly, and its laminæ take a course from one side towards the other (Fig. 360) parallel to these surfaces; the columns of the gymnotus take a direction from the head towards the tail. Hence the laminæ descend from the dorsal

FIG. 360.

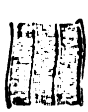


FIG. 361.

towards the abdominal surface, as shown in Fig. 361. And the electrical organs of the gymnotus are supplied by more than two hundred spinal

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nerves, while those of the torpedo are provided with cerebral nerves (§ 1885).

1887. Although the nerves which penetrate the electrical organs of the torpedo are originally of large size, still the quantity of the nervous medulla is greatly increased by the numerous divisions which occur in their subordinate branches, and in the laminæ of the columns (§ 1885) themselves. We have already seen (§ 1701) that the medullary fibres finally merge into others which are yellowish and apparently devoid of medulla. These again divide, and often unite into a network. The result of all this is, that the electric organs are provided with a quantity of nervous elements, such as has never yet been seen in any other organ of the body. But no ganglion-corpuscles can be verified at any point of this peripheric distribution of the nerves.

1888. The shocks which the electrical fishes can give off at will, form a weapon like the poison of venomous snakes. Neighbouring animals are stunned or killed by the electric discharges of these organs, just as though struck down by a powerful shock from an electrical machine, or a flash of lightning.

1889. All the effects which are producible by the electricity of an artificial apparatus, may also be obtained by the discharge of living electric fishes. The formation of sparks, the propagation through conductors, the insulation by non-conductors (§ 215), the elevation of temperature, the deviation of the magnetic needle, and the contractions of the rheoscopic prepared frog—all these unite to certify that we are here concerned with ordinary electrical phenomena.

1890. The central organs of the electric nerves of the torpedo (§ 1885), are two special cerebral lobes of a lemon-yellow colour. The annexed woodcut (Fig. 362) represents the inner surface of the brain of a large Mediterranean torpedo, longitudinally divided along its middle: *f* is the uppermost part of the spinal cord, *e* the medulla oblongata, and *d* the right of the two electric lobes just mentioned. This lobe is characterized by the very large and distinct ganglion-corpuscles which it contains. These are seen by the naked eye as small reddish granules; and they lie closely upon each other, as shown in Fig. 363. Numerous nerve-fibres, which often form loops, pass amongst them with many windings. Many of the ganglion-corpuscles give off grey processes, the transition of which into medullary nerve-fibres is still somewhat doubtful.

1891. After its electric lobes have been excised, the torpedo can no longer communicate shocks at will. But the organs are still capable of reflex discharges, such as will shortly be mentioned.

1892. Various collateral circumstances indicate that the action of the electric nerves is very similar to that of the motor fibres. When the animal imparts its voluntary electric shock, the stimulus is propagated

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in a centrifugal or peripheric direction, from the electric lobes (*d*, Fig. 362) towards the laminæ of the columns (Fig. 359), just as when the

FIG. 362.

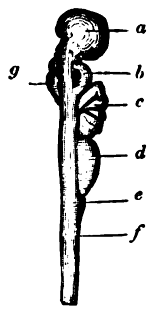
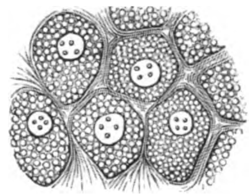


FIG. 363.



motor nerves compel the muscles to contract. The roots of the motor nerves are distinguished by their possessing a large number of thick fibres; and the same is the case with those of the electric nerves of the torpedo (*d e f g*, Fig. 358). When a single trunk or branch of these nerves is irritated mechanically, chemically, or thermically, a corresponding segment of the electric organ (§ 1714) is discharged. Section of the nerves destroys all peripheric propagation of the excitement (§ 1832). And cutaneous irritations, such as in other animals give rise to reflex movements (§ 1717), sometimes produce reflex discharges in the electric fishes. Both of these capacities are lost with the destruction of the corresponding central organ (§ 1937). A weak stimulus which impinges upon the right electric lobe (*d*, Fig. 358) often only acts upon the right electric organ: while a stronger one also arouses the left electric lobe, and hence the whole apparatus. We shall hereafter see that something similar to this obtains in the central organ of the muscles.

1893. The positive current set in motion at the instant of discharge takes a perpendicular course through the laminæ, which are traversed horizontally by the terminal branches of the electric nerves. Hence in the torpedo, this current passes from the back towards the belly; and in the electrical eel, from the head towards the tail.

1894. Although the torpedo and gymnotus stupify or kill other animals, and can produce contractions in the muscles of the prepared frog, their own contractile tissues are unaffected at the instant of discharge. When one of these creatures has given off a series of shocks in rapid succession, its electrical force is, for the moment, exhausted. This state of exhaustion only disappears after a certain period of recovery, like that of the muscles. Hence the exhausted animal may be grasped with impunity. But it shows just as little appearance of stupefaction at this time, as it did of pain or any sensation at the instant of its vigorous

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discharge. In one word, the body of the electric fish appears to be entirely freed from both the sensitive and motor consequences of its own electric shocks.

1895. That external resemblance to a galvanic battery which is presented by the several divisions of the electric organ of the torpedo and gymnotus (§ 1885), has given rise to the conjecture, that the different constituents of the laminæ and their intervening fluid are related to each other like the copper, zinc, and moist conductor of a galvanic pile (§ 230);—the large surface of contact (§ 1886) forming the chief cause of the vigorous discharge. But since the shock only occurs by the aid of an instantaneous nervous act, it follows that the electric organs are not a battery which stands ready for use, only requiring its poles to be connected with each other. The vital action of the nerves is rather an essential link in the process—a condition of the discharge.

1896. We have a right to suppose that the negative deviation of current (§ 1846) accompanies the action of the electric nerves, just as it does that of the other primitive fibres. We might therefore conjecture it to be the chief cause of the discharge. The extraordinary richness of these parts in nerves would cause such effects to be more powerful here than elsewhere. We might even imagine that the resemblance with the galvanic column was only apparent,—and that the whole structure of the electric organs was intended to provide a large surface for the further course of those numerous branches which result from the division of the electric nerve-fibres. The fact that the positive current passes perpendicularly to the nerve-fibres (§ 1893) might perhaps be connected with the change in the electric state of the nervous molecules. The great discharge of the electric fishes would thus be no special phenomenon, but only an instance of those electric changes which generally accompany nervous actions, favoured by the collateral arrangements of the part. But it is obvious that in the absence of more delicate researches into the electric organs and their nerves, we shall only lose ourselves in a variety of uncertain conjectures.

1897. The nervous function has often been compared with electrical induction. A comparison of the two phenomena does really offer many true analogies, in addition to others which are less complete.

1898. The strength of induction increases with the length of the inductive stimulus (§ 246). The muscular contraction increases with the length of nerve traversed by the exciting electrical current. The inducteous current only arises at the instant of closing or opening the inductive one (§ 243). An analogous phenomenon is presented by those prepared frogs which then give double actions (§ 1855), but exhibit no alternating convulsions during the closed state of the circuit. Finally, we have already been informed of the resemblances presented by the electrotonic state (§ 1837).

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1899. But the law of contraction of the living nerve (§ 1853) seriously limits the completeness of this comparison with the phenomena of induction. For the nerve then responds at the instant of closing the circuit, but not at that of opening it. While the inducteous current obtains at both these times.

1900. There is another resemblance which in itself appears much more forced, and which it is just as impossible to follow out. The inducteous closing current is opposed to the inductive one; while the inducteous opening current corresponds with the latter (§ 243). Hence the central current gives the same direction of induction on closing the circuit, as the peripheric does on opening it, and *vice versâ*. In this respect two currents with an opposite direction resemble those prepared frogs in whom there is only a one-sided action,—*i.e.*, in whom the peripheric current presents a closing, and the central an opening, contraction, or *vice versâ* (§ 1862). But since many other circumstances and results (§ 1869) may possibly interfere, this resemblance is somewhat arbitrary as well as imperfect.

1901. The several neighbouring coils of a long spiral wire can act upon each other by induction (§ 247). Here we have a change of their own substance, which has a remote analogy to the electrotonic state (§ 1836) of the nerves. But since the latter continues during the closure of the circuit, the phenomenon may rather be compared with the magnetization of an iron rod in the centre of the inductive coil (§ 248), or with the rotation of the plane of polarization (§ 256). Still as the electrotonic state proceeds from atom to atom for a certain distance (§ 1840), it is obvious that even this parallel is incomplete.

1902. Finally, we may observe that the special influence of rapid change of tension (§ 233) holds good in the inductive, as well as in the nervous, currents. Both inductive and nervous phenomena most readily obey those changes of the electric state which are effected in the shortest possible time. But in many other respects they offer important differences. The extreme sensibility and mobility of the nervous molecules lead to numerous results which cannot be noticed in the inert links of any inductive apparatus.

1903. The mode in which the motor nerves constrain the muscles to contraction is in many respects analogous to that magnetization of iron produced by an inductive spiral. Both substances—the iron (§ 248) and the muscular fibre — then undergo a molecular change. Both gradually become softer (§ 1283), and change their diameter. But the magnetism of the iron disappears immediately on the interruption of the electric current; while, under favourable circumstances, the contraction of the muscles may continue subsequently. And in the muscles, the change of form is altogether different in nature, and far more marked in degree (§ 1275). Exhaustion first shortens the duration

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of the contracted state, and finally renders the contraction itself impossible. And rest can again restore the previous force. All this proves that we are here concerned with a very peculiar and changeable substance, such as necessarily affords a special series of inductive results.

1904. The contactive communication of the change excited in any part of the nervous medulla (§ 1832) requires a certain amount of time. Here, as in other mechanical processes, there is a certain velocity of propagation. But this velocity is even greater for electricity than it is for light. It amounts to 462 millions of yards per second for the former, and 310 millions for the latter. So that if the nervous agent were identical with electricity, it would be propagated in an infinitely small space of time through the short distance which is all it has to traverse even in the largest animals. The arguments which contradict this supposition (§ 1834), and the physiological resistance to conduction (§ 1883)—which is often considerable — appear to indicate that what we call the nervous principle moves far more slowly than the electric fluid. The comparative shortness of the nerves would allow of the greatest punctuality, even with a much smaller velocity.

1905. The nervous principle of the sensitive fibres is translated into a corresponding perception at the centre; and that of the motor fibres, into a contraction at the muscles. So that when any part of a nerve is irritated, the time which elapses between the irritation and the corresponding action represents the period required, both for its propagation along the given tract of fibre, and for the translation which ensues.

1906. On holding the nail of the index finger against a rotating cog-wheel, we can perceive one hundred distinct blows in the second. Reducing into yards the distance which has to be traversed before reaching the central organs, and recollecting that every sensation has a certain after-duration (§ 1536),—it will follow that the propagation and translation have a velocity of more than 100 yards per second.

1907. Helmholtz made use of a galvanic apparatus, in the circuit of which a galvanometer was interposed; and he arranged it in such a way, that its irritation impinged on the nerve at the instant the circuit was closed, while the resulting muscular contraction, on proceeding to a certain extent, itself opened the circuit. In this way the time of closure could be indirectly estimated from the amount of deviation in the magnetic needle. But this period corresponded to the conduction of the stimulus in the primitive fibres, to its translation into muscular contraction, and to a certain duration of the latter act. The sciatic nerve of dead frogs gave an average velocity of 35·4 yards per second.

1908. An expert pianist can flex and extend the middle finger about ten times in a second. Assuming that each separate muscular contraction occupies $\frac{1}{20}$th of a second, and that the distance from the brain to the flexor muscles of the fingers (*p*, Fig. 236, p. 398) is somewhat

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more than a yard, this will give us a velocity of rather more than 20 yards per second for the elaboration of the commands of the will, the propagation of the excitement, its conversion into muscular contraction, and the duration of this contraction. Rapid talking would probably exhibit a much greater velocity.

1909. The nerve-fibres are the links which connect two organs of transfer, a central and a peripheral (§ 1905). In these acts of transfer the sensitive fibres appear to conduct their excitements only in the central direction, and the motor only in the peripheral (§ 1707). But it may be questioned whether this is not solely due to the only means of elaboration being, in the former, at the nervous centre, and, in the latter, at the peripheric muscular substance—whether the fibres themselves are not more indifferent, so as to propagate the change which occurs at the middle of their course in both the central and peripheral direction. We have already (§§ 1836 and 1849) mentioned that, with the electrotonic state and the negative deviation, this is certainly the case. Hence it may possibly hold good for other phenomena.

Fig. 364.

1910. It has been attempted to solve this question by experiment. Supposing *a c* (Fig. 364) to be the central part of a sensitive nerve, and *d b* the peripheric end of a motor one, which have united in the swelling *c d* (§ 1066), — if the excitement proceed both centrally and peripherically, a stimulus impinging on *a c* will produce muscular contractions. But if this be not the case, the excitement of *a c* will not induce contractions, while that of *d b* will. The experiments instituted by Bidder upon the lingual branches of the trigeminal and hypoglossal nerves (§ 1742) of the dog were frustrated by the fact, that the tubercle generally included more or less of the similar nervous stumps: so that it was impossible to be certain that corresponding fibres had not united. Hence we can but conjecture from the theoretical considerations already adduced (§ 1909) that, under more favourable circumstances, these experiments would give affirmative results.

1911. An experiment made by Flourens appears quite decisive as regards the conduction of the influence of the will by the several motor nerves. When the nerves which supply the upper surface of a cock's wing were made to unite with those which run to the lower surface, the subsequent movements presented no difference from those of a healthy animal. Irritation of the central segment led to the same contractions.

1912. We have already (§ 1700) observed, that the anastomoses and plexuses of the nerves intimately mingle their fibres; but that the presence of the terminal plexus cannot be similarly explained. The latter would rather increase the quantity of the nervous medulla, and multiply

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the mutual contact of the various fibres. It might be conjectured that the several fibres here act upon another, and thus effect a mutual communication of their excitements. There are certainly many phenomena which indicate that, within certain limits, something of this kind may occur.

1913. The œsophagus contracts under the influence of any of the different roots of the vagus or spinal accessory nerves. Sometimes the same portion appears to be capable of responding to the stimuli of a number of nerves — at least so far as we can judge by the naked eye. If this were really the case, we might conjecture that the change of one fibre of the terminal plexus induced a molecular change of another in its neighbourhood. The puncture of any part of the heart with a needle leads to a more or less perfect beat (§ 1796). And if this phenomenon is not based upon mechanical causes (§ 1796), it must be due to a communication in the terminal distribution of the nerves. In rare instances, a local irritation of the gastrocnemius gives rise to a general contraction. Supposing that this result is not caused by any deception — by any propagation of the pressure to neighbouring fibres — it would argue a communication in the terminal plexuses of non-ganglionic nerves also. But the observations already adduced (§ 1714) show that, in the larger nervous branches, nothing of this kind occurs. Since the paradoxical contraction (§ 1845) depends on the electrotonic state, and not on the negative deviation of current, the latter could only act, either by the assistance of some special apparatus present in the terminal plexuses themselves, or through a direct influence exerted on the muscular fibres by a change in the electrical condition of the nerve. But the first of these suppositions is pretty decisively contradicted by a phenomenon which we shall now mention.

1914. The inducteous current that arises at the instant of closing the circuit, takes a direction opposite to that of the inductive (§ 245) one. Now if a similar phenomenon obtained in the nerves, the peripheral excitement of the motor fibres would necessarily produce a central one in the neighbouring sensitive elements. We might therefore expect, that the irritation of a motor root which has been cut away from the spinal cord (§ 1720) would give rise to extensive reflex movements (§ 1717). But experience teaches us that this is not the case. From reasons which may be easily conceived, such secondary action (§ 1845) can only be produced by those vigorous electric impressions that give rise to a powerful electrotonic state. It is true that the denuded muscles now and then undergo reflex movements. But these are both rarer and weaker. One can scarcely avoid suspecting that in such cases the sensitive fibres which pervade the muscles co-operate (§ 1721). And since the excitement of a sensitive root which has been separated from the spinal cord does not cause any muscular movements (§ 1720), it is

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evident that the experiments hitherto made rather support the notion of communications in the terminal plexuses, than of inductive actions.

1915. The division of a nerve-fibre (§ 1698) is no physiological difficulty, so long as its branches do not supply organs which are essentially different, or regions which are endowed with independent consciousness. It is true that we are in the habit of supposing ourselves able to recognize the site of the finest puncture with a needle. But we have already seen (§ 1651) that this is not the case. And since perception is indistinct over a space the size of which varies with the degree of tactile sensibility (§ 1653), the branches of division might very well be distributed within this limit. It would then be almost a matter of indifference whether the excitement originally proceeded from one branch of the primitive fibre or another. The simultaneous contraction of large muscular bundles (§ 1913) allows us to apply the same conclusion to those divisions which occur in motor nerves. But, on the other hand, could it be proved that one twig of a sensitive fibre went to the point of the finger, and another to the surface of the hand, it would certainly be a matter of great mystery how we could recognize the locality of a puncture inflicted upon either of these places with bandaged eyes. The special organs of preparation (§ 1650) afford no satisfactory explanation of this phenomenon, which is so essential to the perfection of the senses. Most of the divisions hitherto observed belong to the terminal segments of nerves, or to the nerves of the intestines, where the distinction of locality is less acute. The future must decide whether such an instance as the above,—which would materially shake the doctrine of separate conduction—ever really occurs.

1916. The physiological details with which we are at present acquainted afford no indication of the way in which the nerve-fibres begin and end. They neither imply free terminations, nor contradict looped communications, or confluent networks of similar fibres (§ 1702).

1917. The physiological relations of the ganglion-corpuscles are as yet almost unknown. According to Du Bois, the ganglia of the posterior roots of the spinal cord (§ 1719) offer no obstacle to the propagation of the electrotonic state (§ 1836) or the negative deviation of current (§ 1846) to the fibres of the sciatic plexus (*a b c d*, Fig. 334, p. 507). But many of the fibres which enter the ganglion are uninterrupted by ganglion-corpuscles (§ 1770); so that we are not justified in concluding that these latter exert no influence on those primitive fibres which really are connected with them. On the other hand, it must be recollected, that it is at present undecided how the nervous medulla of the double processes behaves to the ganglion-corpuscle itself — or whether the ordinary conducting substance is not interrupted here, so that the excitement is necessarily propagated by the corpuscles themselves. And the fact that many of these swellings contain far more corpuscles than

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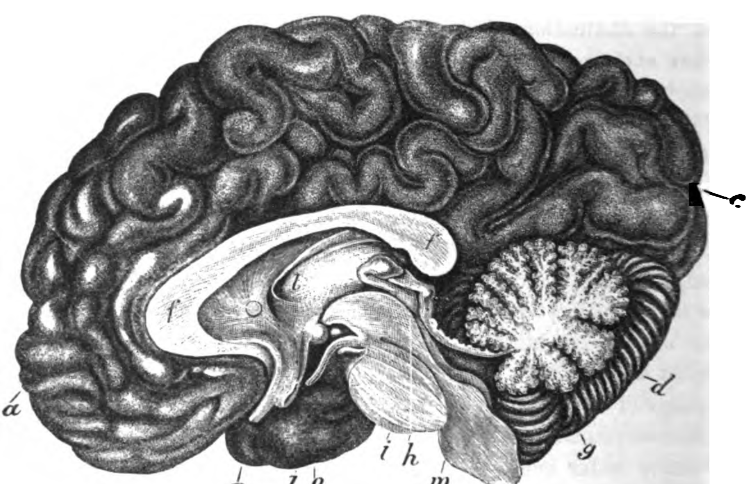
fibres (§ 1770) at any rate shows that the ganglion-corpuscles develope certain independent effects, which are only communicated to the nerve-fibres or other neighbouring tissues.

1918. Many phenomena which are generally ascribed to the action of nerves or ganglia, do not immediately depend upon these, but upon other tissues. For example, the influence of narcotic poisons is usually referred to the nerves. It is thus explained, why the pupil of the eye (*c*, Fig. 150, p. 273) dilates when some drops of a solution of hyoscyamus or belladonna are dropped into the sac of the conjunctiva (*d*, Fig. 150). But comparative physiology refutes this supposition. The enlargement of the pupil occurs only in the mammalia, whose iris contains unstriped muscular fibres; and not in birds, in whom its contractile elements are striped. While in both these classes, the membranes of the iris include numerous nerve-fibres, part of which have traversed the optic (§ 1726), or other ganglia (§ 1786). So that here the special character of the contractile tissues appears to be more important than the influence of the nerves. (Compare § 1301.)

1919. The nervous centre formed by the brain and spinal cord contains two chief substances:—a white, or medullary; and a grey or reddish-grey, or cortical. For example, on looking at a median longitudinal section of a human brain (as exhibited in Fig. 365) we find the grey

FIG. 365.



matter on the surface of the convolutions of the cerebrum (*a b c*) and the cerebellum (*d*); and the white in the corpus callosum (*f*), the fornix (*l*), the septum lucidum (between *f* and *l*), the ciliary body (*g*), &c. While a transverse section of the spinal cord (*a b*, Fig. 366, p. 572) has white fibres externally, and grey matter in its centre.

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1920. These two tissues of the nervous centre essentially correspond to the two chief constituents of its periphery (§ 1689). The white substance contains primitive fibres; and the grey, cell-structures (Tab. V. Fig. 76, *a*) which in many respects resemble the ganglion-corpuscles (Tab. V. Fig. 74.)

1921. An examination of the roots of the spinal cord (*d e*, Fig. 335, p. 510) will convince us that each of their peripheral primitive fibres (Tab. V. Fig. 68) is directly continuous with a central one. The latter possesses a medullary content, and a sheath or neurilemma, like the former. But they generally have either a smaller transverse diameter from the very first, or afterwards undergo a gradual diminution in size. And owing to their greater delicacy, and to their want of that areolar tissue (Tab. III. Fig. 40) which intervenes between the nervous bundles (§ 1694) of the periphery, these central fibres, though originally cylindrical, often become varicose (Tab. V. Fig. 68, *d*) as a result of compression or injury.

1922. From the frequent division (Tab. V. Fig. 70) of the fibres of the peripheric part of the nervous system (§ 1698), we might easily conjecture that something similar occurs in the cerebro-spinal centre. But at present experience has not fully established the accuracy of this supposition. Setting aside the deceptive appearances sometimes presented by different layers, there certainly are rare instances in which we find divisions of single fibres. But it is a question whether these are not produced artificially. For the nervous medulla is easily protruded in various directions by pressure. And this lateral branching is rendered more deceptive by the fact, that the delicacy of the neurilemma is such as to prevent its being recognized without artificial assistance;—such as, for instance, the application of acetic acid. At a further stage of putrefaction, any compression of the medullary content in the act of preparation breaks it up into separate drops (Tab. V. Fig. 75), which are generally single, but sometimes appear to be bifurcated.

1923. While the primitive fibres of the centre are distinguished from those of the periphery by their delicacy, this is still more remarkably the case with its ganglion-corpuscles. The slightest mechanical injury so greatly disturbs their natural connection as to leave nothing visible but a finely granular and grey or reddish-grey substance, with relics of nuclei and nucleoli. This effect is greatly favoured by their want of firm intervening tissues (§ 1921).

1924. The numerous grey portions of the nervous centre exhibit far greater variety of form than the ganglia of the periphery. We sometimes find very large ganglion-corpuscles (Tab. V. Fig. 76), the chief substance of which (*a*) has a pale appearance, and is here and there extremely granular (*b*). The nucleus (*c*) contains a clear vesicle (*d*). The chief substance of other ganglion-corpuscles,—which are often

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smaller,—consists of nothing but granules. It is the latter which decide the colour seen by the naked eye. When many of the former ganglion-corpuscles are aggregated together, the whole has a pale whitish grey colour. While larger numbers of the second variety give the mass a reddish-grey aspect.

1925. The proportion of the general contents to the nucleus also varies greatly. The latter may form either a small (Tab. V. Fig. 76) or a large fraction of the whole: — a difference which greatly affects the form and bulk of the corpuscle. Thus while the ganglion-corpuscles of the spinal cord (Tab. V. Fig. 76) and of the electric lobe of the torpedo (§ 1890) are large enough to be recognized by the naked eye, others require a magnifying power of from two to three hundred diameters. Finally, we meet with some forms which cannot be reduced to the type of cell, nucleus, and nucleolus; but present simple granules, or mere aggregations of minute globules. All of these solid structures are united to each other by a homogeneous, colourless, semifluid, and tenacious substance; which is in all probability very rich in albumen.

1926. We have already (§ 1890) seen that the ganglion-corpuscles of the electric lobe of the torpedo give off grey or greyish-red processes. Something similar is repeated in the grey matter of the nervous centre in other vertebrata (Tab. V. Fig. 76 *e*). Since the ganglion-corpuscles of the periphery emit corresponding processes,—some of which are medullary (Tab. V. Figs. 72, 73), and others devoid of medulla (Tab. V. Fig. 74, *b c d e*),—it becomes a question whether the same process is not frequently repeated in the nervous centre. Now in microscopic examinations we certainly may rarely observe that a grey branch of a ganglion-corpuscle (Tab. V. Fig. 76, *f*) appears to undergo a transition into a true medullary fibre (*g*). But more exact adjustment of the focus (§ 1469 *et seq.*), or movement of the preparation, will generally show that this appearance is deceptive; and that the medullary fibre merely lies on or near the process of the ganglion-corpuscle. Still what has already been stated of the ganglia (§ 1767) will justify us in stating that the central primitive fibres are probably intimately connected with the processes of the ganglion-corpuscles.

1927. Since every primitive fibre of the root of a spinal or cerebral nerve is continued into a fibre of the centre (§ 1921), the brain and spinal cord must contain representatives of all the origins of the cerebro-spinal nerves. But it has hitherto been found impossible to give even an approximative answer to many of the chief questions which here suggest themselves. The brain and spinal cord of the smallest vertebrata contain so large a number of microscopic constituents — these are again so densely and complexly interlaced, and oppose such extraordinary difficulties to research, — and finally, our researches themselves are always limited to such small portions—that it will probably be hundreds of

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years before we gain any clear insight into this important part of the anatomy of the nervous system.

1928. The presence of grey matter in the interior of the spinal cord (§ 1919) at once contradicts the notion that this structure corresponds to a single nerve uniting all the primitive fibres of the spinal roots. The ganglion-corpuscles endow it with a higher import, the physiological results of which will hereafter occupy our attention. But since conscious sensations and the mandates of the will alike proceed from the brain, it becomes a question whether the central processes from the primitive fibres of the spinal nerves ascend to the brain,—or whether they end in the spinal cord, and depute all further communication with the brain to other intervening tissues.

1929. Some observers assert that the central fibres of the spinal nerves terminate by free extremities shortly after their entry into the spinal cord. But this statement is probably based upon deceptive appearances. It is more likely that their transition into ganglionic processes (§ 1767) permits the fibres to terminate, or allows their number to decrease, — always supposing that, in the latter case, there are fewer medullary fibres present near the brain than towards the end of the spinal cord (§ 1927).

1930. Volkmann endeavoured to decide the question by comparing the transverse section of any given part of the spinal cord with the sum of that of the roots of all the nerves which had previously entered it. He argued that, if representatives of all the spinal nerves ascend towards the brain, we might expect that the transverse section of a piece of spinal cord which lies nearer to the brain would be at least as great as the united transverse sections of all the roots of nerves which had hitherto entered it. But this conclusion is not so safe as it appears at first sight to be. The roots of the nerves contain a large quantity of areolar tissue, which is absent from the nervous centre. The primitive fibres of the latter are smaller than those of the former (§ 1921). And the difference of their surfaces of course increases in a quadratic porportion : *i.e.*, a central fibre which has half the diameter of a peripheric one, has but one fourth of its transverse section. It is true that grey matter is added in the spinal cord. But unless it equal the difference just mentioned, the smaller transverse section of the spinal cord will be no valid proof that the central fibres have previously terminated. While the further changes which might be introduced by the processes of the ganglion-corpuscles (§ 1929) and by the divisions of the nerve-fibres, will obviously prevent any safe conclusion from being at present come to.

1931. In fishes, the spinal cord is so narrow at its continuation into the medulla oblongata (to the right of *m*, Fig. 365, p. 566), as to justify our supposing that it cannot contain anatomical or physiological equiva-

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lents of all the fibres which have previously entered it from without. On the other hand, in birds and mammalia, the difference is by no means so extraordinary. At present, however, it is impossible to decide whether these animals are really similar in this respect, or whether the higher development of their brain is associated with a more complete representation of the spinal fibres. The physiological phenomena which here come into consideration will again occupy our attention.

1932. The pure white medullary substance consists solely of primitive fibres; which are densely aggregated together, or closely interwoven with each other. In certain situations, however,—for example in the crura cerebri of the human subject—pigment cells (Tab. II., figs. 29, 30) are interposed between these fibres, and produce a dark colour which is visible to the naked eye. The mass thus coloured is called the *substantia nigra*. Most of the apparently grey matter exhibits scattered primitive fibres under the microscope. When these are in large quantity, the whole mass has a light grey colour. While the uniform mixture of numbers of primitive fibres with a certain proportion of highly granular ganglion-corpuscles produces a yellow colour, such as may often be seen at the innermost margin of the grey matter covering the human cerebral hemispheres (*a b c* Fig. 365, p. 566). The yellow colour of the electric lobe of the torpedo (§ 1890) depends upon similar causes.

1933. The quantity of pure medullary substance in the brain of birds and mammals is many times greater than that contained in the roots of all the cerebral and spinal nerves. Hence many believe that there are special cerebral and spinal fibres; *i.e.* fibres which only belong to the tissues of the centre, and have no direct connection with any peripheric nerves. But however probable this view, the difficulties which oppose anatomical research prevent its being proved in detail, and thus rendered really useful. Part of the medullary substance probably begins by the peripheric fibres being prolonged in very circuitous routes. While another part of it perhaps originates in the medullary processes of the ganglion-corpuscles,—whether by merely uniting portions of the centre to each other, or by connecting them with peripheric fibres.

1934. It has often been attempted to unravel the arrangement of the cerebral and spinal fibres in the higher animals by dissecting their course with the naked eye in preparations which have been steeped in alcohol, nitric acid, a solution of creosote, or other suitable fluids. But it is impossible thus to verify those minute microscopic relations which could alone be decisive. These can only be obtained by patiently examining section after section of the brain with the microscope, and by sketching out general representations in accordance with these observations—a process which has been followed in the medulla oblongata by the unwearied industry of Stilling.

1935. We have already remarked (§ 1917) that the ganglion-cor-

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puscles of the periphery are capable of developing certain special actions, which are continued into the nerve-fibres. This distinction between generation and conduction is perhaps repeated in the nervous centre. Here the grey matter would form the special generator of force; while the primitive fibres of the centre would not only conduct (§ 1904) the excitement to or from the periphery, but would probably execute similar internuncial functions for various segments of the brain and spinal cord.

1936. Such a mutual communication forms one of the most remarkable characteristics of the nervous centre. We have seen (§ 1914) that the excitement of a motor fibre of a peripheric nerve leaves the neighbouring sensitive fibre at rest. On the other hand, in the brain and spinal cord, transfers frequently occur. Reflex movements—as well as the reflex sensations assumed by some physiologists—are due to the conjoined excitement of dissimilar actions; while co-ordinate movements and sensations are produced by the association of similar actions.

1937. Reflex movements are due to a stimulus reacting in a centripetal course towards the nervous centre, where it sets in action certain motor fibres. Hence what was originally a sensitive impression is followed by muscular contractions. The laughter and involuntary defensive movements generally caused by tickling, are familiar examples of this kind.

1938. Reflex movements imply the co-operation of the nervous centre; and, in all probability, of its grey matter. Supposing v (Fig. 366) to be a sensitive fibre which ends in the skin of a limb, the central excitement will proceed to the grey matter $e\ f\ g\ h$ of the spinal cord $a\ b\ c\ d$. Here it indirectly excites the corresponding motor fibres η: either alone, or together with those of the opposite side ϑ, or even with the more remote motor fibres $\varepsilon\ \zeta$. The dotted double lines and arrows in the diagram represent the directions in which the excitements are propagated, but not their several paths.

1939. If a beheaded frog be allowed a little time to recover its irritability, and if a single toe of one leg—for example, the right hind leg—be pinched, or stimulated with a drop of sulphuric or acetic acid, reflex movements may occur;—either in the right hind leg, or in both hind legs, or even in all four extremities. The extent of this motor reaction depends chiefly on the strength of the irritation, and on the degree of sensibility which the preparation possesses. Powerful stimuli give rise to more diffuse actions. The sensibility is generally much weaker immediately after decapitation. But rest subsequently restores it to such a degree, that pressure on the toes gives rise to vigorous reflex movements, in which the beheaded animal leaps violently for some distance. And on placing it on its back, and pinching the skin of its belly, it appears to protect itself, and to thrust away bodies in contact with it. Subse-

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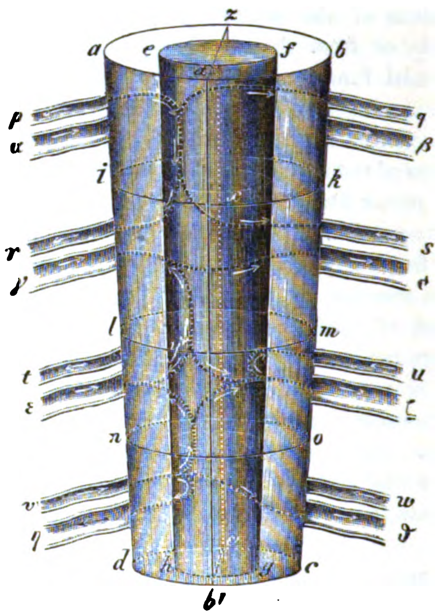
quently this irritability gradually decreases, so that pressure upon a single toe of the right hind leg only gives rise to reactions in this and

FIG. 366.



the other hind leg or one fore leg. During the last relics of irritability, contractions only occur in the muscles of the stimulated hind leg; and they finally become limited to particular portions of this limb.

1940. Reflex movements are easiest brought about by irritations of the skin. For example, pinching the sciatic nerve of a beheaded frog forms a much less effective means of excitement. And on irritating a limited portion of the muscular mass of the hind leg, these reactions are still more frequently absent.

1941. The impression made upon the skin must always exceed a certain minimum. Hence we frequently find preparations in which light pressure and mechanical excitement are quite ineffective, while a drop of acid succeeds. The frequent repetition of slight impressions, such as are made by tickling certain parts of the skin (§ 1660), easily gives rise to corresponding reflex movements.

1942. We have already seen (§ 1533) that the impressions of the senses have a certain after-duration. These reflex actions may last still longer. A single cutaneous irritation often produces a storm of reactive movements, which continue during a considerable period of time. Hence the communication widens the cycle of action in duration as well as in extent. But the conditions of this latter result are more

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limited than those of the first. It presupposes a greater mobility of the elements of the spinal cord,—a mobility which is due either to a previous injury, or to an abnormal disposition. We have here a parallel to the double contractions of the living nerve (§ 1855), or to the tonic spasms which follow some kinds of poisoning.

1943. The natural connection of the conducting paths with each other is just as necessary to the reflex movements as it is to the actions of the peripheric nerves. Hence division of the sensitive fibres (v, Fig. 366) renders it impossible for the corresponding portions of skin to induce reflex movements. While section of the motor fibre (η, Fig. 366) will obviously destroy not only the reflex, but also the voluntary, contraction (§ 1710) of its corresponding muscles.

1944. The reflex movements of the beheaded frog (§ 1939) have already taught us that the transverse section of the nervous centre does not prevent the reflex action of that segment of the spinal cord which still retains its natural connection. Under favourable circumstances, irritation of one hind leg may still give rise to reactions in all four of the limbs (§ 1939). And touching the conjunctiva of the severed head of a mammal may cause its eyelids to close:—the action of the sensitive fibres of the trigeminal nerve (§ 1729) being transferred in the medulla oblongata ($h\ m$, Fig. 365, p. 566) to those motor fibres of the orbicularis palpebrarum muscle ($p\ q$, Fig. 150, p. 273) which are given off from the trunk of the facial nerve (§ 1735).

1945. The nervous centre may be cut across in several places without destroying all possibility of reflex movement. It is only those structures which lie in the immediate neighbourhood of the injured place that seem much affected. More distant organs are merely severed from each other by the transverse section, so as to diminish the extent to which the communication can occur. Thus supposing $p\ q$ (Fig. 366) to be the sensitive, and $\alpha\ \beta$ the motor roots of the fore leg of a beheaded frog, while $v\ w$ and $\eta\ \vartheta$ are the same structures of the hind foot,—transverse section of the spinal cord at $l\ m$ will permit a stimulus applied to v to produce reflex movements of both hind legs $\eta\ \vartheta$, but not of the fore legs $\alpha\ \beta$. The body of a snake or the tail of a lizard may be thus divided into a series of segments; each of which (owing to the simplicity of their nervous distribution) retains its reflex activity.

1946. Incomplete transverse sections which leave only a bridge of grey matter remaining, do not prevent all longitudinal communication. For example, if the spinal cord (Fig. 366) be cut through on the right side to $k\ x$, and on the left to $l\ y$, a stimulus which passes along the sensitive fibres q of the right fore leg may excite reflex movement of all four feet through α, β, η, and ϑ. So that the grey matter at $x\ y$ renders the interference harmless. On repeating the experiment in the living frog, the animal may gradually recover the full

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influence of volition over its hind legs. While on the other hand, complete transverse section of its spinal cord at $n\,o$ destroys the volitional influence that descends from the brain to the hind legs; and at $a\,b$, that which passes to all four extremities. Hence the nearer these injuries lie to the brain, the more extensive is the effect they produce.

1947. Those nerves which occupy the immediate neighbourhood of the complete transverse section generally lose all reflex influence:—as will be the case, for example, with $t\,u$ and $\epsilon\,\zeta$ (Fig. 366) when the transverse section is made at $l\,m$. Hence incomplete transverse sections (§ 1946) which lie immediately behind each other, may exercise the same obstacle as complete ones.

1948. When the spinal cord $a\,b\,c\,d$ (Fig. 366) of a beheaded frog is cut longitudinally through its middle, $z\,a'\,b'\,c'$, all transverse conduction is rendered impossible. But longitudinal communication can still obtain. Hence the application of proper stimuli to the sensitive fibres q of the skin of the right fore leg still gives rise to reflex movements in both the right legs through β and ϑ, but not in those of the left side through α and η. But the living animal can still move all four limbs at will. If the longitudinal section be made more externally, much will depend on the circumstance whether it still occupies the grey matter $e\,f\,g\,h$, or the white $f\,b\,c\,g$. In the former case, a longitudinal communication may still occur; while in the latter, it is destroyed. Now many of the central fibres of sensation and motion run in the white substance ($f\,b\,c\,g$, Fig. 366) in greater or less proximity to each other. Hence there is neither any direct communication of excitements by the central primitive fibres, nor any simple parallel of the paradoxical contraction (§ 1845): but a necessary co-operation of that substance of the nervous centre, which appears grey to the naked eye.

1949. The complete removal of the spinal cord destroys its corresponding reflex movements; and the destruction of the medulla oblongata and brain, those of the cerebral nerves. The peripheric primitive fibres of the nerves therefore behave just like those central fibres which have not yet reached the grey substance. Hence the communication can not depend on the different degrees of delicacy possessed by the structures which ensheath these two kinds of conductive tissues (§ 1921).

1950. Hitherto we have only considered the reflex actions of the voluntary muscles. But similar phenomena may also be exhibited by the intestines. On pinching various parts of the alimentary canal of a beheaded frog, its limbs often move vigorously. And even when a frog has been so far narcotized with ether that the application of pressure to the toes excites no reflex phenomena in its trunk or limbs, particular portions of the alimentary canal may still be made to contract by such interference: or the heart may recommence beating. Thus the

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ganglia neither check the advance of sensational stimuli towards the centre, nor the propagation of motor ones from it. Changes that proceed from the peripheric extremities of the sympathetic may be transferred to cerebro-spinal nerves which obey the mandates of the will: and, conversely, stimuli that impinge upon the tactile skin may be transferred through the spinal cord to the intestines which are governed by the sympathetic. But since, in both these respects, the ganglionic nerves furnish negative results more frequently than the cerebro-spinal nerves, we are justified in supposing that here, as in the sensations of pain, certain special conditions are present.

1951. In the heart there is a peculiar and exceptional appearance, which is sometimes repeated under other circumstances. The closure (§ 1241) of a galvanic circuit sometimes disturbs the rest of the excised heart, and gives rise to a complete pulsation of its auricles (*a b*, Fig. 98, p. 185) and ventricle (*c d e*, Fig. 99). On repeating the experiment several times, the heart often continues to beat spontaneously. But the same galvanic current then frequently has no effect in accelerating the pulsations already present. This indifference on the part of the active heart is also sometimes seen in etherized frogs. The same pressure on the toes which aroused the quiescent heart, often loses all action after the restored pulsation has lasted for some time.

1952. Since the grey matter of the nervous centre forms a link which is essential to the phenomena of transfer (§ 1948), the question suggests itself, whether that of the periphery — or the ganglion-corpuscles — may not independently permit of similar effects. But the facts hitherto known do not establish the possession of such a capacity by the ganglia. When the mucous membrane of the palate or œsophagus of a mammal is tickled with a feather, reflex movements of deglutition or vomiting are produced. But, on the other hand, after removal of the medulla oblongata these results no longer obtain; although the commencement of the peripheric course of the vagus nerve (§ 1744) has a large ganglion, which contains the corresponding motor fibres. The separated loops of the intestine of a recently killed rabbit (Fig. 76, p. 134) are thrown into more vigorous and extensive undulatory movements (*d a*, Fig. 76) when left in their natural attachment, or when cut out with their mesentery (*hi*), than when this is completely removed. Hence it has been supposed that these reflex or associated movements are produced by the corresponding ganglia of the sympathetic. But we may easily convince ourselves that the absence of those parts which contain the ganglia does not preclude the possibility of extensive and repeated undulatory movements. So that they would seem only to favour and assist the result.

1953. Since it is not every cutaneous irritation that is followed by a reflex movement, the transfer requires the support of certain collateral

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conditions. On comparing an uninjured with a beheaded animal in this respect, we find that the latter affords far more marked reflex phenomena as soon as its first period of exhaustion is past (§ 1874). The influence of cerebral action may frequently be seen in our own persons. The laughing and reactive movements which tickling would otherwise produce, may be suppressed by the will—either for a time, or altogether. Several of the reflex phenomena which will shortly be mentioned—such as sneezing or deglutition—are partially under our own control. Others, however, are quite involuntary.

1954. Many of our corporeal acts are based upon a mechanism of reflex and corresponding movement. Such are the closure of the eyelids when a particle of dust has fallen into the sac of the conjunctiva (§ 890); the alteration of the pupillary aperture in light or darkness (§ 1496); the sneezing which succeeds mechanical or chemical irritation of the mucous membrane of the nose; the involuntary movements of deglutition in the pharynx and œsophagus (§ 381); the cough which follows irritation of the internal surface of the larynx or trachea; the effect of tickling; the scream which is sometimes uttered on the unexpected puncture of the skin by a needle—with many similar phenomena. These examples show that every portion of the skin conditionates a more or less determinate variety of reflex movement. We meet with a certain co-ordination, which is effected by the exciting sensitive fibres and their central organs.

1955. This statement is confirmed by a more careful examination of those reflex movements which occur in the beheaded animal. Those motor nerves of the centre which lie near the entrance of the exciting sensitive fibres are the first to be thrown into action. Hence the reflex movement predominates in that limb the skin of which is irritated (§ 1940). On irritating the anterior part of the skin of the belly in the decapitated frog, its fore legs are moved forwards. But on shifting our attack towards the middle of the belly, they move backwards. In like manner, on irritating the posterior half of this surface, the hind legs are pushed forwards. While, on compressing one of the toes of the hind leg, these limbs are extended, so that the animal frequently springs forwards. The application of a stimulus to the hind legs may produce reflex movements of the fore feet, and *vice versâ*. Hence the communication in the spinal cord may be either from before backwards, or from behind forwards. But when, on the other hand, we irritate the conjunctiva, it is only the orbicular muscle of the eyelids ($p\,q$, Fig. 150, p. 273) which contracts; and not the other muscles of the face, which are also supplied by the facial nerve (§ 1735). In like manner, tickling the soft palate acts on the commencement of the alimentary canal, but not on the heart or the lungs, which equally depend on the vagus (§ 1749) nerve and the medulla oblongata.

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In one word, the apparatus of the nervous centre possesses certain keys, which are played upon as soon as an impulse is furnished by stimulation of the corresponding sensitive fibres. This often gives an appearance of adaptation to the reflex actions seen in the beheaded animal. But a more careful examination teaches us that there is here neither volition, nor purpose, but a definite organic action.

1956. The ducts (§ 867) and receptacles (§ 923) of the glands, which are provided with unstriped muscular fibres, frequently offer a reflex movement like that of the intestines. Friction of the glans penis (*g'*, Fig. 154, p. 285) leads to a reflex action of the seminal ducts (*q w*, Fig. 154) and the seminal vesicles (*n x*); so as to be followed by emission. The copious flow of tears which succeeds irritation of the conjunctiva (*d*, Fig. 150, p. 273) is an act of reflex * secretion. To the same category also belongs that increased effusion of saliva which follows mechanical irritation of the soft palate.

1957. The question—whether certain corresponding segments of the brain and spinal cord do not co-operate in all reflex secretory acts of this kind — cannot at present be answered with certainty. It is true that the flow of tears ceases on the destruction of the medulla oblongata, so that the transfer would seem not to be effected by either the Gasserian (*x*, Fig. 322, p. 484) or the optic ganglion (§ 1726). But we must not forget that injury of the medulla oblongata more or less destroys one essential condition of secretion; namely, circulation. On the other hand, the observation that this copious flow of tears appears not to occur after section of the trigeminal nerve between the Gasserian ganglion and the brain, points very expressively to the influence of the nervous centre. It is true that a person suffering from disease of the spinal cord, who has paralysis of both legs, and not the least trace of sensibility during sexual intercourse, may still have seminal emissions. But here it is possible that the organic degeneration is of such a kind as to destroy conduction to the brain, without affecting the transfer to the corresponding motor fibres.

1958. We have seen (§ 1707) that the vital actions of the nerve-fibres take a one-sided and centripetal or centrifugal course, while the electrotonic state (§ 1836), as well as the negative deviation of current (§ 1846), passes in both directions. This has already led us to conjecture, that the latter is a mere collateral phenomenon, which accompanies, but does not constitute, the living function of the nerves. The laws which regulate the transfer at the nervous centre confirm this conclusion.

1959. When we irritate a sensitive fibre (*v*, Fig. 366, p. 572), the

* But this effusion sometimes follows so instantaneously, as to justify the conjecture that it begins by a reflex muscular contraction, to which the slower secreting process is only subsequently added.—EDITOR.

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excitement takes a centripetal course. The change which causes the reflex movement then runs centrifugally in *n*, so as not to contradict the law of a vital one-sided propagation. But when we attack the motor fibre (*n*, Fig. 366) in the middle of its course, no reflex sensation or pain (§ 1720) is produced. Yet since the negative deviation of current obtains equally in its more central segment, could this alone determine a transfer, it might occur. While on the other hand, the supposition that the final result depends on a one-sided, centrifugal, and vital propagation, at once explains the insensibility of the anterior roots of the nerves.

1960. Many have supposed that, under certain unusual circumstances, reflex sensations may occur. But all the facts thus explained are open to other interpretations. The painful sensations which follow violent muscular movements are possibly due to changes in the peripheric tissues and their nerves. It is probable that the pains which accompany contractions of the uterus also proceed from the terminations of its nerves. And even were this not the case, the phenomenon might be otherwise explained. The grey matter which is connected with the central motor fibres, and which evokes their action, is perhaps itself agitated so strongly, as to cause a transfer to the neighbouring representatives of the sensitive fibres. It is probable that we might thus explain the fact, that morbid muscular contractions sometimes cause such violent pain, as to persuade a thoughtless surgeon to amputate (or otherwise uselessly mutilate) a limb.

1961. Co-ordinate movements are due to the habit that certain muscles have of acting simultaneously, whenever any one of them gives the first impulse. Here we have an alternate play, such as is represented by $\gamma\ \vartheta\ \iota\ \zeta$, (Fig. 366, p. 572). These phenomena are sufficiently explained by the statements in § 1960.

1962. Like the reflex contractions (§ 1954), the co-ordinate movements materially assist many vital acts. Among the movements which are necessarily associated we may enumerate the simultaneous adjustment of both eyes (§ 1443), the regular and successive movements of deglutition (§ 381), the normal act of respiration (§ 739), the different exceptional varieties of this movement (§ 755), the abdominal pressure (§ 393), and many other phenomena. Here again certain keys in the nervous centre are played upon in a prescribed manner (§ 1955). The will has either no action at all, or exerts only a limitary and quantitative influence.

1963. All the instinctive movements belong to the class of phenomena now under consideration. Many of them—such as deglutition or respiration—are executed by the new-born infant (§ 742); while others—such as the maintenance of equilibrium during the various movements of progression (§ 1320)—are only learnt gradually. Others—such as,

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for example, the simultaneous movement of some groups of the facial or digital muscles—are imperfections, which can only be gradually overcome by effort. Here the neighbouring and corresponding parts of the nervous centre influence each other so easily, that nothing but practice ever enables us to govern them singly.

1964. Consensuous impressions are caused by the simultaneous excitement of different sensitive fibres, (such as are represented by *p q r* and *s*, Fig. 366, p. 572). In many cases it is possible that the transfer occurs at the peripheric extremities of the nerves. The irradiation of the retina (§ 1531) is an example of this kind. But in most other instances the communication only occurs at the nervous centre. The general thrill which follows the scratching or brushing a small portion of the skin belongs to this class of phenomena, and may be explained by the theory mentioned in § 1960.

1965. Many of the morbid consensuous impressions occur in those fibres, the central segments of which run in the neighbourhood of the representatives of the exciting nerves (§ 1939). Hence pinching the bulbous nerve of the stump of an amputated thigh sometimes gives rise to sensations of pain in the skin of the remainder of the limb, and in the neighbouring abdominal walls. In other cases, overloading the stomach produces violent pain in the foot, which disappears on the artificial production of vomiting.

1966. Since the local accuracy of sensation and voluntary motion are in themselves some of the highest perfections of the animal body, every transfer is, to a certain extent, a disturbance—such as can only be excused or required by collateral considerations. This is especially true of those organic arrangements which give rise to many reflex (§ 1937) and co-ordinate (§ 1961) movements. Most of the instinctive movements correspond to physical laws, which cannot be completely fathomed by the most toilsome research. The explanations already given of the simultaneous movements of the eye (§ 1443), and the maintenance of equilibrium (§ 1320), may illustrate the truth of this statement. It seems as if Nature had determined to prevent all chance of error, and had therefore constructed an instrument capable of playing upon itself. A similar arrangement is obviously implied in these involuntary serial contractions which—like deglutition (§ 381) and parturition,—can only be executed by a succession of determinate acts.

1967. The influence of practice on our movements of progression plainly shows how gradually we learn the use of the nervous instrument with which nature has equipped us. The same statement also applies to many other voluntary movements:—such as the combination of various sounds (§ 1425) in speaking, or of various fingers in playing music, together with many similar acts which the practised performer executes at

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once, and without bestowing any consideration on their details. All of these actions end by becoming essentially instinctive.

1968. The continual afflux of scarlet blood is a condition very important to the normal molecular constitution of the nervous centres. This proposition especially holds good with mammals and birds :—but is less strictly applicable to reptiles and fishes, in whom the interchange of gases is less active (§ 840), and irritability more independent (§ 1261). When the blood carried to the brain of a man becomes deficient in quantity, or dark in quality, its alteration is soon followed by deceptive sensations, head-ache, fainting, unconsciousness, suffocation, convulsions, and finally death. Hence the brain of a beheaded person soon dies. Persons who are hanged, or who are suffocated in carbonic acid, or in an irrespirable gas that is not directly noxious, perish in a similar manner.

1969. Many poisons greatly change the disposition of the whole nervous centre, or of certain of its parts. When pure strychnine or one of its salts is introduced into the stomach or into a wound, the animal falls into the most violent convulsions as soon as a sufficient quantity of the poison has been absorbed, and transmitted with the blood to the nervous centre. The slightest mechanical disturbance of a frog which has been thus treated at once excites a vigorous tetanic state of varying duration. A similar phenomenon is seen in many other kinds of poisoning. Frogs who have been dosed with opium, or who have had a solution of belladonna, oil of turpentine, or sulphuric ether injected into the rectum, sometimes exhibit general tetanic convulsions on the local application of external stimuli. But that contraction of the muscles of the limbs which succeeds the use of ether, appears not to reach the great intensity produced in poisoning by strychnine.

1970. The poison need not necessarily reach the spinal cord through the blood. If we behead a frog, excise its heart, lay bare its spinal cord, and moisten this with a solution of strychnine, we may often obtain complete tetanic convulsions of the muscles of the foot.

1971. After removing the brain and spinal cord, we may moisten the peripheric nerves with a solution of strychnine (even while the heart continues to beat), without producing this change of disposition (§ 1969). Hence this poison only acts through the nervous centre, and chiefly through its grey matter. Of course the solution of strychnine must not contain any other substance capable of altering the contents of the nerves. Tincture of opium and ether check the action of those parts of the peripheric nerves which they thoroughly penetrate. But no general tetanic convulsions follow.

1972. One or two sixtieths of a grain of strychnine suffice to throw a mammal into violent tetanic convulsions. And since only a fraction of this quantity is carried by the blood to the spinal cord, it is evident

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that the change of disposition must depend upon extremely minute quantities of the noxious agent. The alteration thus brought about may in course of time disappear. A rabbit may be thrown into powerful tetanic convulsions by a little strychnine, and yet be quite well on the following day. The same recovery may be seen in frogs after enemata of weak solutions of belladonna or opium, or ether.

1973. Great attention has been given to the action of ether and chloroform; on account of the insensibility which they produce allowing the infliction of violent injuries without pain. Opium had previously been administered to persons who were about to undergo operations; and laudanum had been injected into the blood of animals before painful experiments. But the use of this drug is far too unsafe and troublesome to be compared with that of ether as recommended by Jackson, or with that of chloroform, which has been substituted for ether in accordance with the proposal of Simpson.

1974. The usual ether apparatus consists of a receiver, at the bottom of which lie sponges moistened with the drug. The walls of their numerous cavities furnish a large evaporating surface. Hence the atmospheric air which fills the remaining space of the vessel, and is frequently changed during respiration, is easily saturated with the vapour of ether. Proper connecting tubes allow the access of air. The person breathes through a mouth-piece with opposite valves, which cause the air laden with vapour of ether to enter the lungs, while the gases subsequently expired pass off into the surrounding atmosphere. The action of chloroform is so energetic that we have but to pour a few drops of this fluid on a handkerchief, and hold it under the nose, to produce stupefaction in a very short time.

1975. A person beginning to inhale the vapour of ether is often attacked by irritative cough. To this frequently succeeds a slight and pleasant intoxication, which is connected with an increased impressibility of the senses, or with deceptive sensations, and great mental hilarity. This is sometimes followed by delirium or raging frenzy. Ultimately sensation — or, at any rate, the perception of sensuous impressions — is altogether lost. The capacity of hearing appears to be retained longer than the other senses. The person no longer feels the most violent pain, or at least becomes incapable of perceiving it with the clearness and emphasis of reflection and memory which are present in persons not thus intoxicated. Hence an entire limb may be removed without the patient being awakened from his sleep and dreams. The act of dividing the skin and the large nerves — which forms the most painful part of an operation — leads to none but very inconsiderable movements, and slight or transient expressions of pain. It sometimes happens that the patient, who is wandering in his thoughts, sees the operation commenced without evincing the least excitement. Many, however, scream

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out. But when subsequently awakened, they no longer remember the past pain. The tactile sensibility of the skin often gives rise to a peculiar phenomenon. There is a period of stupefaction by ether, in which the patient feels a puncture with a needle, and recognizes a stick pressed upon the skin as a blunt and broad body (§ 1651), but yet undergoes cutaneous incisions without offering any resistance.

1976. At a further stage of the action of ether, the face becomes pale. The objective actions (§ 1433) of the senses altogether disappear. The muscles become extremely relaxed. They lose their elasticity, and retract less when cut through (§ 1272). The patient is plunged into a deep sleep, which is accompanied by snoring or stertorous breathing. The external resemblance to a dying person becomes more and more prominent. If pure air be now allowed to enter the lungs, the patient soon recovers completely. At most, he suffers some time from swimming of the head, and an ethereal odour of the breath and eructations; or occasionally from nausea, melancholy, and prostration. He now recollects his dreams during the ethereal intoxication; and indicates what he underwent during the narcotized state in accordance with the delusions which then exclusively occupied his mind. Finally, it sometimes happens that, immediately on waking, the patient continues the discourse in which he was interrupted by the stupefying effect of the ether.

1977. The effect of chloroform resembles that of sulphuric ether; but is much more powerful and rapid. Many persons on whom ether has little or no effect are soon stupefied by chloroform. The latter also more frequently gives rise to attacks of violent excitement, and the involuntary evacuation of the urine or fæces, followed by deep sleep attended with snoring or stertorous breathing. The administration of chloroform is, on the whole, more dangerous than that of ether. The latter only kills when it is inhaled for too long a time without interruption. On suspending the experiment, the abnormal phenomena at once diminish; and the dangerous symptoms almost always disappear after a short period of rest. But the action of chloroform frequently goes on subsequently. The stupefaction which it produces lasts for a long time; and may even be considerably increased after the re-admission of pure air into the lungs. Hence its effects are not quite so manageable as those of ether.

1978. Mammals and birds can only recover provided that their respiration, however enfeebled, continues during the period of stupefaction. But this condition does not apply to frogs. These animals often exhibit no trace of respiratory movement during a long period of time; and yet recover their previous activity, if the pulsation of the heart has not ceased.

1979. The immediate appearance of mental disturbance, which is quickly followed by insensibility (§ 1975), shows that the brain is soon

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attacked by the ethereal vapour. The spinal cord appears to be next affected. At a later period, those muscles which it supplies can no longer be excited to action from the cord or from their nerves,—whether by a mechanical stimulus, or by the electro-magnetic machine (§ 248). The medulla oblongata is afterwards paralyzed. But its various actions do not all disappear at the same time. For the respiratory movements which it induces continue to occur, even after irritation of the nerves no longer causes contractions in those muscles of voluntary motion that depend upon this part of the nervous system, and injury of the medulla oblongata itself does not produce any pain. In mammals, the irritability of the posterior sensitive roots seems to disappear before that of the anterior motor ones.

1980. Those segments which are the last to succumb to the action of the ether, appear to be the first to recover from it. The reflex movements of the eyelids (§ 1944) are restored before those of other parts of the face; while the latter generally contract in obedience to a cutaneous stimulus before the limbs. The fore legs generally precede the hind ones in this respect.

1981. The viscera of the chest and belly only succumb after the muscles of the trunk and limbs. The toes of the narcotized frog may often be pinched without any appearance of reflex movements (§ 1950); while similar irritation of the stomach is more successful. The heart always continues to beat after the muscles of the body have ceased to give any answer whatever to irritation of their nerves.

1982. From these facts some have deduced the independency of the sympathetic nerve (§ 1781). But there are two phenomena which decidedly contradict this view. The longer duration of irritability in the stomach and heart is due to these structures being chiefly or wholly governed by the vagus nerve (§ 1752); and hence by the medulla oblongata, which is the last part to be paralyzed (§ 1979). Besides this, the posterior lymphatic hearts (*h i*, Fig. 349, p. 531) continue to beat tranquilly, when reflex movements can no longer be induced by cutaneous irritation of the toes. Their action may be destroyed by electrical stimulation of (§ 1793) the spinal cord, the free muscles of the body remaining perfectly quiescent. But since these structures are governed by non-ganglionic spinal nerves (§ 1793), the greater resistance of the stomach and heart cannot be due to the ganglionic character of their nerves, or to the special nature of the sympathetic.

1983. The continuance of the cardiac pulsation explains why the blood traverses the capillaries of the frog's web (§ 651) — sometimes with an undiminished velocity — even when no trace of respiratory movement is perceptible. Any serious disturbance of the gaseous interchange in higher animals renders their arterial blood of a dark red colour (§ 826). The slow occurrence of an intense degree of narcotism

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is attended by a considerable decrease of the animal heat, both in the rectum of the mammal and the cloaca of the bird. But this collateral effect may be suspended by the rapid appearance of phenomena endangering life, or by death itself.

1984. The action of the vapour of ether does not require the aid of the nervous centre (§ 1971) or the peripheric nerves. On placing a prepared frog (Fig. 206, p. 368) in a space of air saturated with this vapour, its susceptibility gradually decreases. And the excised heart of a frog (§ 598) after some time ceases to beat. The cilia of a separated membrane (§ 1195) are also sooner or later arrested. The seminal corpuscles (§ 1215) would probably offer similar results. In favourable instances, all of these—prepared frogs, hearts, and cilia—recover when exposed to the air, and may thus be repeatedly narcotized by the vapour. Similar phenomena are exhibited by chloroform. And when this is poured into a wound, the latter loses its sensibility to pain before the access of the general effects.

1985. These facts indicate that the vapours of ether and chloroform cause important changes in the molecular constitution of the tissues of the nervous centre, the nerve-fibres of the periphery (the muscular fibres?), the cilia, and probably the seminal corpuscles. Here again we have an action produced by extremely minute quantities, such as we have already become acquainted with (§ 1972) in the case of other poisons. The recovery which afterwards takes place is probably due to an evaporation of the ether and chloroform; and shows that these drugs cannot induce any collateral decompositions capable of preventing a return to the normal admixture of the parts.

1986. We have already (§ 1854) seen that the changes caused by strychnine or ether in the living animal only diminish the susceptibility of the nerves, without essentially altering their disposition or tone. The same conclusion may be deduced from the etherized prepared frog. The only effect of ether is, that it finally deprives the nervous medulla of its capacity for the contactive propagation of excitement from molecule to molecule. But it neither rotates the atoms, nor alters their phenomena of polarization (§ 1833)—as would, for example, be the case, if a prepared frog which formerly presented one-sided homogeneous contractions (§ 1862) offered heterogeneous ones after moderate narcotism. In rare instances, however, the vapour of acetic acid certainly does effect such an important revolution in the molecular state.

1987. A peculiar serous secretion—the cerebro-spinal fluid—fills the cerebral cavities, the aqueduct of Sylvius (*h*, Fig. 365, p. 567), and the spaces which intervene between the arachnoid and pia-mater (§ 1719). A morbid increase of this fluid gives rise to dropsy of the brain and spinal cord.

1088. When the denuded dura mater of a rabbit is punctured between

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the skull and the first cervical vertebra, a certain quantity of cerebro-spinal fluid streams out in a more or less curved jet. The animal then becomes incapable of maintaining its equilibrium as before. It often staggers as if intoxicated, is very liable to fall in rapid running, and moves its legs more uncertainly than usual. Magendie refers these phenomena to the absence of cerebro-spinal fluid—the resulting change of pressure and friction giving rise to important disturbances of the nervous centre, such as materially damage the precision of its action. But since a considerable portion of the spinal cord or brain may sometimes be laid bare without the production of these results, it follows that, at the junction of the head with the vertebral column, certain important collateral causes are present. Longet has attempted to show that the disturbance of equilibrium is chiefly due to that separation of the cervical muscles which necessarily precedes exposure of the dura mater here. According to him, the crura cerebelli (near *m*, Fig. 365, p. 567) are, under these circumstances, disproportionately injured, and react upon the remaining parts of the nervous centre.

1989. The skull of the adult forms a hard capsule, the walls of which are almost everywhere unyielding. It is completely filled by the cerebral meninges or membranes, the cerebro-spinal fluid, the brain, the vessels, and the nerves. Something similar is the case with the vertebral column. But here the limitary walls contain a larger quantity of soft tissues, which by extending outwards, permit some increase of the absolute internal space.

1990. The compressive elasticity of solid and fluid bodies (§ 69) is so inconsiderable, that we may at once dismiss it from our consideration with respect to the ordinary changes of pressure to which the nervous centre is exposed. The entry of more blood into the vessels of the skull and brain can only occur by way of dispossession or replacement:—by its causing cerebro-spinal fluid to flow off towards the more yielding spinal canal, or blood to pass out into the numerous sinuses around this part, and into the veins of the neck. But when the slight increase of space permitted by the various intervertebral tissues has once been claimed, the blood in the cavity of the skull can receive no further addition except by being substituted for lymph, or for the bulk which the nervous substance has itself lost from some morbid cause. Hence there is a limit to congestion of the brain (§ 1046)—a limit which depends upon physical circumstances, and which, except under extraordinary collateral circumstances, is soon reached. The abnormal increase of cerebro-spinal fluid in the various dropsies of the nervous centre (§ 877), is met by the same obstacles. Finally, these explain why, in beheaded persons, the cavity of the skull loses less blood than the external soft tissues of the head.

1991. The phenomena just mentioned obviously imply that the

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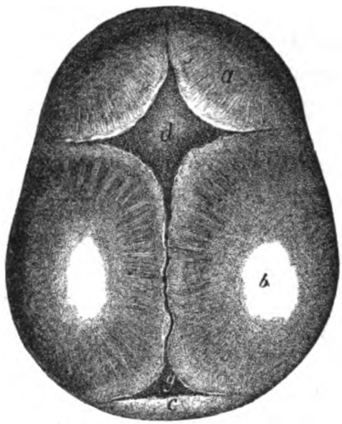
hard skull forms an unyielding case around the whole space which encloses the brain. But in very young children this condition does not hold good. The skull is then soft and cartilaginous in many places; — such as the great fontanelle (*d*, Fig. 367) between the frontal and parietal bones (*a* and *b*), and the small fontanelle (*g*) between the parietal (*b*) and occipital bones (*c*). The smaller index of elasticity (§ 55) possessed by these structures, enlarges the limits of the afflux or efflux of fluid. And when a piece of bone has been removed from the skull of an adult by the operation of trepanning, or when the whole calvarium of an animal has been taken away, similar differences will obviously obtain.

FIG. 367.



1992. The denuded brain of a mammal exhibits two kinds of movement; arterial and respiratory. The former coincides with the pulse, the latter with the breathing. The results of the latter are greater than those of the former. And deep respiratory movements especially increase its amount. In small mammalia like the rabbit, no arterial movement of the brain is at first visible.

1993. The impulse and increased arterial distention which are produced by the systole of the left ventricle (§ 610) raise and dilate the mass of the brain. And since the arteries which unite the internal carotids with the vertebrals pass between the lower surface of the brain and the skull, the former of these parts must then undergo a considerable elevation. Deep expiration propels the arterial blood with increased force (§ 625) in the peripheric direction; at the same time that it obstructs the centripetal course of other fluids, such as the lymph and the venous blood. These phenomena explain the respiratory movement of the brain. They also illustrate, why the stream of cerebro-spinal fluid which gushes out of an opening in the uppermost part of the spinal meninges (§ 1988) describes a wider curve during deep expiration, and a smaller one during energetic inspiration. By compressing the chest of a recently killed dog we may imitate these results artificially.

1994. Under circumstances otherwise equal, the movements of the denuded spinal cord are smaller than those of the brain. Its respiratory displacement is distinct, while only traces of the arterial movement can be recognized.

1995. From the facts already stated (§ 1990) we may conjecture that, in

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the uninjured animal, these phenomena take a different form. For the afflux of new matter is so soon checked by the resistance of the limitary walls, that the change must at any rate have a narrower range of action. But since part of the cerebro-spinal fluid occupying the cavity of the skull can deviate towards the vertebral column (§ 1990), it is probable that the arterial and respiratory movements are not altogether absent. Hence a man suffering from giddiness is liable to headache and dimness of sight when he exerts an unusual amount of abdominal pressure (§ 393). But this is less remarkable in the adult than in the infant (§ 1991):—in whom we may satisfy ourselves, both by sight and touch, that the great fontanelle ascends and descends with a rhythm corresponding to that of the respiratory movements.

1996. The slightest injury of many parts of the nervous centre gives rise to violent expressions of pain. While other portions may be pinched or torn, without any more notice on the part of the animal than if its hair or nails were being cut.

1997. Every irritation that impinges either on the posterior columns of the spinal cord, or on those parts of it which occupy the neighbourhood of the posterior sensitive roots of the nerves (*d d*, Fig. 335, p. 510), gives rise to excruciating pain. On the other hand, the medullary substance of the anterior columns is as insensible as the motor roots (§ 1720) which penetrate their interior. But their irritation gives rise to violent muscular contractions. The lateral columns of the spinal cord belong to the class of mixed structures. For they not only produce contractions in the corresponding muscles of the body, but also possess a certain sensibility,—which is, however, weaker than that of the posterior columns.

1998. Among the sensitive portions of the brain and medulla oblongata, we may enumerate the following:—the surfaces of the medulla oblongata (*m*, Fig. 365, p. 567) and pons Varolii (*i*); the various medullary crura of the cerebellum (*d g*); the crura cerebri (between *i* and *o*); the deeper medullary masses of the cerebellum (*g*); the interior of the optic thalamus, and (partly) of the corpus striatum of the cerebral hemispheres (*a c*). On the other hand, we may slice away the superficial grey or mixed substance (§ 1924) of the cerebral and cerebellar hemispheres, without any notice on the part of the animal. This fact is the more extraordinary, since it is these parts of the brain which minister to the higher acts of thought, and to the perception of sensitive impressions. Many other parts are devoid of all trace of sensibility to pain:—such are the walls of the aqueduct of Sylvius (*h*, Fig. 365), the superficial segments of the corpora quadrigemina (*i*), the pineal gland, the boundaries of the third ventricle, the anterior and soft commissures, the corpus callosum, (*f f*), the fornix (*l*), the septum lucidum (between *l* and *f*), together with a great part of the corpus striatum and optic

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thalamus, and many peripheric portions of the white substance of the cerebral (*a b c*), and cerebellar (*d*) hemispheres.

1999. We have already seen that complete transverse section of the spinal cord destroys the sensation and voluntary motion of all the organs which derive their nerves from its posterior (or inferior) segments. When its thoracic portion is completely torn across in the human subject, the feet become paralyzed. A similar injury in the middle of the cervical portion reacts upon all four extremities. But if the grey matter of the segment below the site of the injury retain its powers, reflex movements of the paralyzed parts may still take place.

2000. Destruction of the right half of the spinal cord affects the corresponding tissues of the right side (§ 1948); while those of the left still retain their vital functions. Hence there is no decussation of these in the spinal cord.

2001. Similar results are afforded by the posterior part of the medulla oblongata. But the further we proceed forwards from this point, the more prominent a decussating action becomes. Hence injuries of the right half of the nervous centre paralyze or weaken certain corresponding parts of the left side of the body, and *vice versâ*. In the autopsy of a person affected with paralysis of the left half of the body, the region of the right corpus striatum and optic thalamus is generally found destroyed by hæmorrhage or disease. The details of these phenomena of decussation will occupy our attention hereafter, with reference to the compulsory movements seen in animals after certain injuries of the brain.

2002. The thoracic and abdominal viscera, which derive their (chiefly ganglionic) nerves from the vagi (§ 1744) and the sympathetic (§ 1787) trunks, are acted upon by many parts of the nervous centre, as well as by the roots of the spinal nerves. Such an influence is possessed, not only by the spinal cord and medulla oblongata, but also by some segments of the cerebrum and cerebellum. So that the same chief portions of the nervous centre are capable of governing both the viscera and the voluntary muscles of the limbs. It is possible that corresponding fibres pass from each of these to the brain. But our imperfect knowledge of all these anatomical details (§ 1927) leaves us open to the conjecture, that the chain is perhaps completed by transfers which mutually unite various portions of the nervous centre. Since the electrotonic state (§ 1836), is repeated in the tissues of the nervous centre, it may have played an important part in many of those experiments which have been instituted with the electro-magnetic apparatus. But as the influence exerted on the intestines by the brain and spinal cord may be verified with simple mechanical or chemical stimuli, there must at any rate be some special communication, or direct dependency.

2003. When the heart of a newly killed frog has ceased to beat, it is

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just as incapable of being excited to new contractions from the spinal cord as from the sympathetic (§ 1788). On the other hand, when the shocks of the electro-magnetic machine are sent through the medulla oblongata of the living animal, the pulsation of its heart soon ceases. But on a further continuance of the irritation, the heart recommences to beat,—just as after the similar treatment of a limited portion of the vagus (§ 1754).

2004. We have already remarked (§ 1788) that the application of a rapid succession of electric shocks to the vagus arrests the pulsation of the mammalian heart, while a similar treatment of the sympathetic is capable of increasing its frequency. The same contrast is repeated by the medulla oblongata and the upper part of the spinal cord; the former arresting, and the latter quickening, the beats of the heart. But in fishes, the anterior and middle segments of the spinal cord are capable of stopping its pulsation;—probably by collateral electrotonic effects.

2005. No part of the nervous centre acts so decisively on the action of the heart as the medulla oblongata. This also retains its influence after all other segments of the centre have become powerless from exhaustion, or from the time which has elapsed since death. On laying bare the nervous centre of a living frog, and applying electrical irritation to the whole medulla oblongata (*D* to *F*, Fig. 368), the heart is always arrested during diastole. The rudimentary cerebellum (*D*) and corpora quadrigemina (in front of *D*) sometimes give rise to the same results; while the optic lobes (*B*) only do so under circumstances of special collateral excitement. In careful experiments, however, the cerebral hemispheres (*A*) offer nothing of the kind. But in all these cases it may be questioned whether the results are more than apparent;—whether they are not solely due to conduction through the moist tissues, and to the electrotonic state. The corpus callosum and the deeper lateral portions of the cerebral hemispheres, as well as the crura cerebri and the corpora quadrugemina, frequently evince a most unquestionable action on the heart of the recently killed mammal.

FIG. 368.

2006. We shall hereafter see what an influence the medulla oblongata exerts on the respiratory organs. This segment of the nervous centre also controls the actions of the pharynx and œsophagus. But in dogs, cats, or rabbits, which have been killed some minutes previously, the contractions of the œsophagus are not vermicular; but are generally either inverted or continuous (§ 1302).

2007. The stomach and small intestines of the rabbit, horse, cat, and dog, may often be thrown into contraction from the nervous centre.

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In mammals that have just been killed, the middle and upper part of the spinal cord, the medulla oblongata, the deeper portions of the cerebellum, the crura cerebri, the optic thalamus, and the corpus striatum, frequently give rise to more or less deep constrictions of the stomach; as well as to an active peristalsis of this organ and the duodenum. Since these results are repeated after division of the vagi and the lowest part of the œsophagus, it follows that they sometimes depend, not on the influence of these nerves (§ 1755), or on a mechanical propagation of the œsophageal contractions, but on an action of the sympathetic fibres.

2008. The large intestines and the urinary bladder may be influenced by almost all the spinal cord, the medulla oblongata, and the parts of the cerebrum above mentioned (§ 2007). In the recently killed rabbit, vigorous peristaltic contractions of the ureters are often produced by the upper and middle part of the spinal cord, the medulla oblongata, the optic thalamus, and sometimes also by the deeper parts of the cerebellum. The subsequent electrical irritation of the ureter itself often causes no contractions. The vasa deferentia, Fallopian tubes, and uterus are obedient to the whole of the spinal cord and medulla oblongata; and sometimes to the cerebellum also.

2009. In recently killed rabbits, irritation of some parts of the centre—such as the spinal cord—often leaves the muscles of the body in a state of rest, while it is instantly responded to by the intestines. While birds frequently exhibit precisely the reverse of this. In other instances, the ureter presents vigorous undulations, while the alimentary canal remains at rest. In short, the various parts of the centre which govern the different organs of the periphery lose their irritability in very unequal degrees.

2010. The action of the lymphatic hearts has already (§ 1793) led us to the conclusion that the rhythm of the cardiac movement does not imply the co-operation of the peripheric ganglia. The relations of these structures to the nervous centre may assist to dispose of another very similar theory. Those who assert the physiological independence of the sympathetic or the ganglia (§ 1781) are obliged to explain the influences exercised by the brain and spinal cord on the thoracic and abdominal viscera as the results of a communication: excitements of the centre being transferred, in the interior of the ganglion, to the independent ganglionic fibres. But the nerves which rule the lymphatic hearts (§ 1793) are devoid of ganglion-corpuscles, and derive their fibres directly from the spinal cord. It therefore follows, that the pulsating heart does not require any special and independent nervous system, but may depend immediately on the nervous centre, like other parts of the body.

2011. On beheading a frog at the junction of its medulla oblongata and spinal cord (between *E* and *F*, Fig. 368, p. 589), the action of its

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lymphatic hearts is at first often arrested. But they subsequently recover themselves, and then continue to beat for a long time. Since the anterior of these hearts is chiefly supplied by the third spinal nerve (*d e*, Fig. 348, p. 531, and 12, Fig. 336, 510), and the posterior by the tenth (*g*, *h i*, Fig. 349, p. 531, and 19, Fig. 336), they are most plainly acted on by those segments of the spinal cord which immediately give rise to these nerves (§ 1947). The destruction of those segments weakens the lymphatic hearts. During the period which immediately follows the injury, they remain at rest. But subsequently they acquire new force, and may continue to beat for many days, especially after the application of a mechanical irritation. The anterior lymph-hearts are, however, more easily overcome than the posterior. The latter exhibit the peculiarity, that they no longer contract at once, but in numerous successive divisions or sacculi. So that here the influence of the spinal cord determines the unity of the cardiac beat, but not its rhythm or continuance.

2012. On exposing the spinal cord of the frog to the influence of the electro-magnetic machine, the action of its lymphatic hearts is instantly arrested. But in the frog poisoned with strychnine, we may easily convince ourselves that, after the division of the seventh (*d*, Fig. 349, p. 531), eighth (*e*) and ninth (*f*) spinal nerves, these organs take no share in the general tetanic convulsions. And their alternate play may continue days or weeks after the destruction of the posterior half of the spinal cord.

2013. The influences exercised by the nervous centre on secretion, nutrition, and animal heat, are, if possible, even more obscure than those of its periphery (§ 1806). Here daily experience is perhaps more instructive than the physiological experiments which have hitherto been made. The flow of bile produced by anger, the diarrhœa sometimes caused by fright, the nearly colourless urine passed by hysterical women after violent mental impressions, the noxious milk given out by an angry wet nurse—all these phenomena indicate how remarkably irritation of the brain and spinal cord can react on the organs of secretion. The bed-sores which often occur in cases of palsy due to disease or injury of the spinal cord prove that here also the capacity of the tissues for resistance is depressed (§ 1811). And when the retention (§ 942) or incontinence (§ 941) of urine from which such men suffer renders it advisable to introduce a catheter into the urethra, the trabecular tissue of the penis becomes strongly distended, while the size of the member is greatly increased. Still this priapism is less than that producible by sexual excitement. And similar erections appear to occur spontaneously; *i. e.*, from any accidental transitory irritation.

2014. Some have attempted to deduce the independence of the sympathetic system from the fact, that in frogs whose brain (*A B D*, Fig. 368,

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p. 589) and spinal cord (*F F*) have been destroyed, circulation, digestion, nutrition, and the secretion of urine, still continue. Where the medulla oblongata (*E F*) remains uninjured, the pulsation of the heart lasts much longer than where this segment of the nervous centre has been destroyed. But the continuance of the cardiac pulsation implies that of the circulation generally: and the passage of the blood through the glands and the other tissues will be followed by secretion (§ 850) and the exsudation of nutritional fluid (§ 1010), as a necessary physical result. The general fact—that the acts concerned in the metamorphosis of matter are not interruped under these circumstances—does not suffice to imply the co-operation of nerves independent of the brain and spinal cord. While supposing the fibres which supply the ducts of the glands, the vessels, and the other tissues now under consideration, to be more or less completely governed by the nervous centre, we might expect that its destruction would give rise to some subordinate changes, in spite of the continuance of the normal cardiac pulsation.

2015. Our knowledge of the chemistry of the secretions is not sufficiently advanced to decide this question in a satisfactory manner. There is no doubt that the removal of the spinal cord of the frog depresses the capacity of resistance in the paralyzed parts. If the animals are kept some time in dirty water, the hind legs become dropsical, and often ulcerate, or even undergo a partial putrefaction. In short, we finally observe all the phenomena described in § 1811, frequently in a remarkable degree. Similar destructive changes are seen in mammalia;—besides corresponding differences in their local animal heat.

2016. Many limited injuries of the nervous centre lead to what are called compulsory movements;—in other words, to the repetition by the animal of a series of certain prescribed (and hence partly involuntary) movements, the nature and direction of which depend on the character of the previous interference. The animal goes straight forwards or backwards, rotates its recumbent body around the long axis, revolves (while standing) around one of its hind legs, or runs round and round like a horse which is being led in a circle by a cord. These movements frequently occur from inward impulses; *i.e.*, without any apparent excitement. In other cases, the animal remains for some time perfectly quiet. But on any attempt at a change of attitude, the prescribed act unrelentingly interferes, like the movement of a clock-work when its catch is released; and the animal only returns to its previous state of rest, on becoming exhausted by a repetition of such movements.

2017. Transverse section of the spinal cord does not give rise to any noticeable compulsory movements. But incisions on one side of the medulla oblongata sometimes produce curvatures of the trunk, and squinting movements of the eyes.

2018. When any part of the right half of the pons Varolii (above *i*,

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Fig. 365, p. 566) of a rabbit is cut through longitudinally, the animal generally rotates towards the same side,—and the more vigorously, the greater the distance of the injury from the median line. But when the other side is symmetrically injured in the same manner, the mutilated animal remains quiet. Here the compulsory movement arises from a lateral disturbance of equilibrium; and may to some extent be compared with the depression of one scale of a balance, on removing the second. According to Magendie, a longitudinal section exactly in the median line gives rise to oscillations from one side to the other, but not to the compulsory movements just mentioned.

2019. Section of one of the crura cerebelli (at *m*, Fig. 365,) also produces vigorous rotations, the direction of which depends chiefly on the locality of the injury. When the wound is situated near the medulla oblongata, the animal rotates towards the injured side. But if it be posterior and superior to this, in the medullary substance (*g*) of one hemisphere of the cerebellum, the result will be exactly the reverse. The eye of the same side rolls hither and thither, or is directed upwards and backwards; while that of the opposite side looks forwards and downwards.

2020. The influence thus exercised by the situation of the nervous tissues which are divided and exposed in the experiment, seems almost equally valid in the remainder of the cerebellum. A longitudinal section of one hemisphere (*d*, Fig. 365) produces circular movements, which, in accordance with the site of the incision, are directed towards the injured or the uninjured side. On adding a symmetrical section of the other hemisphere, the animal sometimes goes straight forwards. While the longitudinal division of the vermiform process (and thus of the whole cerebellum) into two pretty equal lateral halves, only leads to oscillations (§ 2018) which somewhat resemble those of an intoxicated animal.

2021. Many observers state that animals whose cerebellum has been removed or extensively injured involuntarily go backwards on attempting to execute any change of place. But it is only in a few rare instances that this phenomenon is clearly observable. And even in these, it is at times scarcely to be recognized.

2022. Removal of the right half of the corpora quadrigemina (between *f* and *h*, Fig. 365) causes birds and mammals to rotate towards the injured side. Under these circumstances, the right eye stares backwards, and the left forwards.

2023. According to Schiff, division of one crus cerebri or the posterior part of one optic thalamus produces circular movements which are directed from the injured side; while other sections of the optic thalamus give rise to rotations towards it. This explains why a longitudinal section in the inner half of one hemisphere of the brain (*a b c*, Fig. 365)

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produces movements towards the opposite side. But these effects do not follow division of the corpus callosum (*ff*) and fornix (*l*) in the middle line from before backwards. On subsequently removing the upper half of one cerebral hemisphere, they may, however, occur.

2024. Many observers state that animals both of whose corpora striata have been extirpated, are constantly impelled forwards. They suppose that in the uninjured brain, two forcible impulses are maintained in mutual equilibrium—one which urges the animal in the anterior, and another in the posterior direction. The former is lost by removing the cerebellum, and the latter by extirpating the corpora striata. Hence, in the first case, the mutilated animal involuntarily moves backwards; while, in the latter, it is impelled forwards. But we have seen that injuries of the cerebellum are not always accompanied by this retrograde movement (§ 2021). And that far more vigorous impulse forwards which has been observed after extirpation of the corpora striata frequently succeeds other injuries — such as, for instance, division of the optic nerves. While when the corpora striata are extirpated without interfering with the optic nerves beneath, the movement sometimes fails to occur.

2025. The tendency to compulsory movements may continue for some days. Under such circumstances, the irritability is often morbidly increased. A moderate irritation, such as would be little or no excitement to the quiescent animal, frequently gives rise to a continuous storm of violent rotations;—by which, for example, the rabbit may be either completely buried in the hay in which it lies, or flung upon some neighbouring object. But when dogs survive this period, their compulsory movements gradually become weaker; and, finally, everyting returns to the normal state.

2026. In man, local degenerations of the cerebral substance produce continuous rotations far more rarely than in mammals, birds, and frogs. We have already seen (§ 2001) that those injuries of the optic thalamus and corpus striatum which frequently accompany apoplectic strokes only produce paralysis of the opposite limbs, and sometimes also of the facial muscles and external rectus (§ 1452). They never produce movements of rotation. The paralysis itself by no means extends to all the contractile tissues of one side. The greater part of the muscles of respiration (§ 747) generally retain their previous relations with the nervous centre. In rare instances, destruction of one crus cerebelli has been observed to be attended with repeated movements in a circle on the application of any external or internal excitement. But the destruction of a great part of one cerebellar hemisphere from abscesses is rarely followed by these phenomena. Here again paralysis constitutes the chief occurrence. The rotations of animals are perhaps mainly due to their various muscular structures being weakened, and

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then subjected to one-sided stimuli, and to an abnormal alternation of their action.

2027. Continuous rotation of the body produces that subjective deception of sensibility which we designate by the name of giddiness or *vertigo*. During its continuance, the paths apparently taken by external objects are chiefly determined by the attitude of the head, and by the direction of movement. Many have attempted to compare these phenomena with the circular compulsory movements of animals. But their conjecture—that only half of the brain is here specially excited—has hitherto not been proved. The subsequent deception of sight, and the fall which succeeds it, rather contradict than support their theory. Finally, there is nothing to indicate that animals are affected with giddiness while undergoing such compulsory movements.

2028. Although the brain and spinal cord form one continuous whole, still they include various groups of tissues, each of which enacts a more or less definite and special function. But everything concurs to hide from the eye of the physiologist the mechanism of this—the most important organ of the animal body. We have already been made acquainted (§ 1927) with the insuperable difficulties of its anatomy. The various parts of the brain on which different names have been bestowed no way correspond to groups of tissues that possess a physiological import, but only to portions that are capable of being recognized externally. Hence such names often divide a single structure, and unite different ones. So that, while they facilitate the topographical description of the nervous centre, they do not map out its true organs. All physiological experiments rest on an insecure basis, since we are devoid of that microscopic knowledge which could alone render them decisive (§ 1927). And, as we can never determine how far disease of one part has reacted upon the remainder, pathological observations on the human subject furnish no materials such as physiology can safely elaborate. We are thus almost exclusively referred to experiments upon animals. These offer almost equal disadvantages. For not only do we thus operate on an organ which is unlike the human nervous centre, and less perfect than it: but, after all, the sensations of these creatures cannot be satisfactorily ascertained.

2029. The application of a stimulus to some of the large peripheric nerves causes whole groups of the corresponding muscles to contract, and thus produces various general movements of the limbs. But the reflex phenomena (§ 1937) expressly indicate that the aid of the grey matter of the spinal cord is required for the harmonious alternation of flexors and extensors, adductors and abductors; as well as for that mutual play of the muscles by which many attitudes are effected. In short, the cord contains a mechanism, in which definite series of keys are played upon under the influence of the will, the instinct, or incident centripetal stimuli:—

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the several keys either sounding separately, or in more or less suitable accords. It was formerly supposed that the central organs of the flexors were chiefly contained in the anterior half of the cord, while those of the extensors occupied its posterior half, or *vice versâ*. But hitherto this conjecture has not been confirmed by experiments.

2030. Some facts easily verified in the spinal cord of the frog lead to the conclusion, that the segments nearer to the head exercise an influence different from that of the subsequent portions upon the same limbs. On cutting across several spinal cords at the first, the second, the third vertebra, &c., we see that the hind-legs are more strongly flexed, the nearer the seat of the injury is to the brain itself. On passing beyond the fifth vertebra, extension of the hind feet replaces the previous rotation at the hip-joint. But the strength of the extension constantly diminishes as we pass further backwards.

2031. From hence we might at first conclude that, in the horizontal spinal cord, the central organ of the flexors is anterior, and that of the extensors posterior. But the accuracy of this opinion is at any rate very doubtful. For both the shocks of the electro-magnetic machine, and simple mechanical stimuli, give rise to vigorous extension when applied to the anterior part of the cord. We should therefore have to assume, that, in these instances, the powerful stimulus was propagated further backwards; and that the extension was due to the facility and energy with which it was responded to by those central organs that lie close to the entrance of the nerves (§ 1947).

2032. When a frog is beheaded at the first vertebra, and its limbs extended, the headless trunk generally adjusts itself after some time; the hind legs being bent at the hip, the knee, and the ankle. But when the spinal cord is cut across between the fifth and sixth vertebra, the animal preserves its extended attitude.

2033. The energetic action exercised by the medulla oblongata on the pulsations of the heart (§ 2005) and the movements of respiration (§ 2034) endows it with an influence on the duration of life such as is not possessed by any other segment of the nervous centre. The cerebrum, cerebellum, and spinal cord of an animal may be removed without immediate death. But the destruction of the medulla oblongata of a bird or mammal destroys its life in a very few minutes.

2034. The central organs of respiration are contained in that part of the medulla oblongata which gives origin to the roots of the vagus (*q*, Fig. 336, p. 510), and in the segment immediately behind this. The nearer a transverse section of the spinal cord is to the medulla oblongata itself, the greater the number of muscles which it withdraws from the play of respiration. But even after the spinal cord has been cut through as far forwards as possible, the facial muscles are still capable of maintaining their respiratory movements. And conversely, injury of the

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pons Varolii from which the facial nerves (§ 1735) emerge destroys the respiratory play of the face, but not of the trunk. While the destruction of that part of the medulla oblongata above mentioned instantly annihilates all respiratory movement.

2035. But the central organ of respiration claims only part of the structures here present. The remainder govern the heart, the organs of deglutition, the abdominal viscera, and various muscles of the trunk and limbs. Many of the latter muscles never share in the movements of respiration. This arrangement may assist to explain the fact, that the muscles which share in the act of respiration become more numerous, the more energetically a person breathes, or the greater his danger of suffocation (§ 749).

2036. In recently killed mammalia, we may often convince ourselves that the central organs of the respiratory apparatus retain their irritability longer than most of the neighbouring portions of the medulla oblongata. On irritating this part mechanically or chemically, we frequently get a deep respiration, when no further trace of convulsions appears in the muscles of the limbs, and no movement of deglutition can be produced.

2037. On cutting through this segment of the nervous centre in animals, they fall into violent alternating spasms which are soon followed by death. The transverse section of one lateral half does not necessarily give rise to this result. In like manner, we often find old effusions of blood in one side of the human medulla oblongata: while more extensive injury, or pressure on all sides, is capable of destroying life in a few minutes.

2038. The whole nervous centre of a frog may be slit up longitudinally, without affecting the simultaneous play of the respiratory muscles of both sides of its body. So that longitudinal section of the medulla oblongata does not separate the symmetrical respiratory muscles of both sides into two groups capable of independent or inharmonious actions. The same phenomenon may be distinctly seen in mammalia, when the brain is removed, and the medulla oblongata cut into from before backwards.

2039. We have already observed (§ 704) that, under favourable collateral circumstances, the heart of a recently killed animal is revived by artificial respiration. When the medulla oblongata of a living rabbit from which the brain has been removed is exposed to the powerful shocks of the electro-magnetic machine, not only the pulsations of its heart, but also its respiratory movements, cease. Here the heart is in a state of relaxation or diastole, while the respiratory muscles are contracted—at any rate at the commencement of the experiment. But weaker stimuli of the same kind are capable of increasing the frequency of respiration. Since electrical irritation of the medulla oblongata fre-

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quently arrests the pulsating heart of a recently killed animal, without causing the appearance of any movement in the respiratory apparatus, or any convulsions in the muscles of its limbs,—it follows that the heart possesses its own central organs, which may die even later (§ 2036) than those of the muscles of respiration. While another experiment on the frog teaches us that the medulla oblongata exerts an influence on the heart, not only through the breathing (as seen in artificial respiration), but in some more direct way. For the pulsation of the heart continues longer after extirpation of the lungs or section of the vagi, than after the destruction of the medulla oblongata. And the breathing may be suspended for some time by the action of ether without any stoppage of the heart (§ 1978).

2040. It has already been remarked (§ 1758) that destruction of both spinal accessory nerves injures the voice of the mammal, but not its respiration. Hence we may conjecture that the central organs of the voice, which regulate the lingual action (§ 1408) of the laryngeal muscles, are not identical with those of respiration. It is probable that the peculiar origin of the spinal accessory nerve (by roots that arise low down from the cervical portion of the spinal cord) has some intimate connection with these facts.

2041. According to Magendie, injuries of the junction between the medulla oblongata and the spinal cord cause a gradual but violent inflammation of the eyes in the domestic mammalia. Here we might conjecture some special injury of those nerve-fibres which ascend through the superior cervical ganglion of the sympathetic towards the head (§ 1786).

2042. It is on the medulla oblongata that the normal and successive movements of deglutition (§ 381) essentially depend. Hence after an animal has been killed some minutes, these are no longer producible by artificial irritation (§ 2006). But on the other hand, they may occur after the removal of the brain: and are not destroyed by cutting through the middle of the cervical region of the cord.

2043. From what has already been stated, it follows that the medulla oblongata can directly or indirectly govern the greater part of the striped and unstriped muscles of the thorax and of the abdominal viscera. And the addition of the pons Varolii makes up a segment of the nervous centre that forms a kind of ganglionic focus for the actions of all the spinal, and the greater part of the cerebral, nerves.

2044. Many have felt obliged to assume that painful impressions may be perceived in the medulla oblongata For even after the cerebrum and cerebellum of a mammal have been removed, it still shrieks on receiving an injury of the skin. And powerful counter-movements generally follow. But these facts do not necessitate the assumption just mentioned. We have (§ 1953) seen that the removal of the brain especially favours the appearance of those reflex movements which proceed from the spinal

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cord. The same proposition holds good of the medulla oblongata. The central fibres from the skin, or the central tissues in physiological union with them, lie close to the nervous centre of the voice—a proximity which would greatly facilitate the reflex production of cries of pain (§ 2040). Just as the apparent purpose of the reflex movements seen in the limbs of a beheaded frog does not prove the presence of conscious volition (§ 1955),—so in an animal whose brain has been removed, the start on receiving a pistol shot, or the scratching of the nostrils after the inhalation of the chemical irritant ammonia, may be immediately deduced from the above mechanism of the central organs.

2045. The corpora quadrigemina (below *f*, Fig. 365, p. 566) have a remarkable reaction on the eyes. The two right ones directly govern the pupil (*c*, Fig. 150, p. 273) of the left eye, and *vice versâ*. Still, owing to a transverse communication of the excitement, both pupils can at once indicate the irritation of one half. Their removal produces blindness, but does not destroy the mobility of the iris.

2046. A mammal whose cerebellum has been removed is more or less incapable of executing certain general movements. It stands less steadily than before; and, when lying down, makes a series of useless efforts to rise, and to avoid an obstacle or a blow. Birds which have been thus mutilated tire themselves out by unusual and ineffective fluttering movements. Still most of the various muscles remain under the control of the will. Hence it is only their co-ordinate combination that is lost. Many physiologists have therefore supposed the cerebellum to be the organ that co-ordinates the more complex movements of the body. But however plausible this view, still we may doubt whether these unsuitable muscular actions, and the useless exertions which accompany them, are not a consequence of the loss of certain local conditions of progression or flight—such as, for instance, the proper fixation and adjustment of the spinal column.

2047. Phrenologists have assigned the cerebellum a special influence on the sexual organs. They have asserted that a greater development of this part of the nervous centre results in an increased activity of the sexual impulse. But experience does not confirm this theory. It is true that the seminal ducts, the oviducts, and the uterus of the domestic mammalia may be thrown into contraction from the cerebellum. But the same effect can be produced through other parts of the nervous centre (§ 2008). The cerebellum of geldings is quite as large as that of stallions. And Flourens found that a cock from whom this part of the nervous centre had been removed still made distinct attempts at copulation.

2048. Degeneration of the human cerebellum does not necessarily give rise to imbecility or any other affection of the mental powers. Destruction of one of its hemispheres has sometimes been accompanied

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by an uncertainty of gait, a tendency to rotatory movements (§ 2026), or hemiplegia — usually of the opposite side (§ 2001). But limited disease of the cerebellum may exist without any considerable disturbance of the action of the voluntary muscles.

2049. A longitudinal section through the centre of the corpus callosum (*ff* Fig. 365, p. 566) and fornix (*l*) of a rabbit is unattended by either rotatory movements (§ 2023) or insensibility, so long as no collateral phenomena interfere. The animal generally becomes irritable and ill-tempered; and its heart beats very quickly. It subsequently suffers from diarrhœa, which is sometimes accompanied by vomiting: and certain parts of the intestine become so distended with gases, as to cause the belly to protrude. The rabbit now and then gnashes its teeth: and is sometimes attacked by convulsions. It finally becomes paralytic and comatose; and dies, often during a violent convulsive fit.

2050. In recently killed mammalia, we may convince ourselves that the corpus striatum and optic thalamus of one cerebral hemisphere govern the muscles of the limbs, and the numerous thoracic and abdominal viscera (§ 2005). The statement of some observers—that the anterior parts of the cerebrum or the corpora striata act chiefly on the hind legs, and the posterior or the optic thalami on the fore legs—has hitherto received no confirmation. One corpus striatum can excite movement in the extremities of both sides—at least in recently killed animals (§ 2001). The destruction of the corpus striatum does not necessarily give rise to extensive paralysis. But when the optic thalamus is also removed, the animal falls towards the opposite side. Still, when assisted to rise, it proceeds some distance properly enough.

Just as the secretions of the intestines are visibly disturbed by section of the median tissues of the brain (§ 2049), so something similar obtains after injury of the optic thalami or crura cerebri. The fæces are evacuated more copiously, and have a slimy character; and are often admixed with blood. Rumbling noises in the bowels betray an increased development of intestinal gases. The appetite disappears. The previously alkaline urine (§ 972) becomes acid; and, according to Schiff, sometimes contains traces of albumen. This observer also states that an acid character of the urine is a certain indication of the approach of death.

In the human body we may sometimes observe how remarkably a cerebral disturbance can react on the condition of the abdominal viscera. Serious injuries of the brain are often accompanied by vomiting, diarrhœa, increased effusion of bile, and disease of the liver.

2051. In the recently-killed rabbit, irritation of the hippocampus major sometimes gives rise to contraction of the facial muscles. In this case, the decussation (§ 2001) is generally distinct.

2052. According to Flourens, the transverve section of one cerebral

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hemisphere of a bird leaves behind it more permanent injury than the longitudinal one. But provided that only one hemisphere is injured, or that the two are not cut through uniformly, the mental powers may sooner or later reappear.

2053. In the dog the chief phenomena which result from the excision of one cerebral hemisphere are paralysis of the optic nerve, weakness of the muscles of the opposite side, a liability to be easily startled, and rotatory movements. The latter may, however, subsequently disappear. The mental powers are not much affected. Nor are they necessarily lost by disease of the greater part of one hemisphere in the human subject.

2054. When both hemispheres of a mammal are removed in successive layers, the mental functions gradually decrease in proportion to the loss of substance. On reaching the ventricles, complete unconsciousness is generally produced.

2055. A dog or a rabbit whose cerebrum has been completely removed generally lies as if sunk in deep sleep. Everything which does not absolutely touch its body appears to pass unnoticed. The mental elaboration of the sensations is completely annihilated. But loud sounds still rouse the blind animal; and painful cutaneous impressions cause it to shriek and attempt to defend itself. All these phenomena, however, depend merely on the reflex actions already mentioned (§ 2044). The mutilated animal does not take any food spontaneously. But food thrust into the commencement of its pharynx is swallowed and digested as usual. In this way birds deprived of their brain may be kept alive more than a year by artificial feeding. External stimuli or internal irritations (which probably proceed from the viscera) occasionally lead to some change of place. But these movements are often very peculiar and abnormal. The blindness of the animal, and its deficiency of mental power, frequently cause it to move clumsily, and strike against obstructions which it would otherwise have avoided. All such movements soon cease, and are again replaced by a lethargy of many hours' duration.

2056. In the human subject, limited structural disease of both cerebral hemispheres often produces weakness of intellect, imbecility, or lethargy. Here the visible disease may occupy either the anterior, middle, or posterior sections of the cerebrum, without much influencing the general results.

2057. The exsudation of large quantities of liquid into the ventricles of the brain, or a morbid increase in the amount of cerebro-spinal fluid, may produce weakness of intellect, coma, sopor, and other abnormal states of mind. Hence such appearances are often found in the brains of cretins, as well as in persons who have died of inflammation of the brain, nervous fever, or other similar disorders. But at present it cannot be proved that the abnormal phenomena exhibited during life

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depend exclusively on either the collateral causes which precede and permit the increased exsudation (§ 1990), or on the pressure it produces. It is probable that these are partly due to minute disturbances in the molecular relations of the nervous tissues, such as will perhaps never be visible to our senses.

2058. It is usually stated that the brain forms a larger fraction of the weight of the body in man than in any other vertebrate animal. In the adult, it is about $\frac{1}{30}$th to $\frac{1}{40}$th; and in the infant, $\frac{1}{8}$th to $\frac{1}{9}$th. But many small mammals and birds exhibit a larger proportion than the adult human being.

2059. There is no doubt that an abnormal smallness of the brain is connected with idiocy. And it is very probable that persons distinguished for their intellectual powers possess brains which are large, either as a whole, or in particular parts. But it is far more difficult to prove this excess, than the converse diminution. For the abnormal circumstances which precede death may themselves produce a deceptive increase of weight (§ 2057). And we have a right to suppose, that the mental endowments are materially influenced, not merely by the quantity of the organ, but also by its quality, and relative activity. The high forehead which is frequently regarded as an external indication of mental power certainly does generally depend on a greater development of the anterior cerebral lobes, and of those parts of the skull which cover them. Still this does not justify the conclusion, that it is these segments of the cerebral mass which exclusively regulate the higher mental capacities or many of the faculties that express them;—such as, for instance, eloquence. Comparative and pathological anatomy unite to testify, that the middle and posterior lobes of the brain, and many of its internal swellings (such as the pes hippocampi and pes accessorius, which lie in the posterior cornu of the lateral ventricle of each hemisphere) are at least as important as its anterior segments.

2060. It has often been maintained, that in men distinguished for intellect, the convolutions of the two cerebral hemispheres (*a b c*, Fig. 365, p. 566), are more numerous, and less symmetrical. But the fact itself is by no means established. And beside this, experience teaches that the advantages which are perhaps associated with the convoluted arrangement may be quite annihilated by internal disease. The brain of a cretin often exhibits large and complicated convolutions, while its cavities are distended by copious fluid exsudations.

2061. The microscopic characters of the cerebral substance undergo important changes in the course of development. In the new-born infant, a fine section of its superficial layer exhibits a minutely granular basis, together with cell-like nuclei (Tab. V. Fig. 77) such as are met with in the pure grey matter of the adult. A similar section from the adult brain shows numerous (and distinctly medullary) primitive fibres, in addi-

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tion to the preceding structures. The above peculiarities are even more distinct in the embryo,—which exhibits voluntary and reflex movements at a period when no distinct white substance or oily content can be observed in its peripheric nerve-fibres, and when its nervous centre only includes a basis and cellular elements resembling those of pure grey matter. Hence the general actions on which these movements are founded do not exclusively depend on the peculiar forms possessed by the nervous tissues of the adult.

2062. The lateral repetition of most of the organs, and of the nerves by which they are governed, partially explains why so many segments of the centre are in pairs also. But since the same arrangement holds good in portions which are not immediately connected with peripheric organs, there must be other reasons for it. It has often been supposed that the commissures or middle portions fulfil the purpose of linking the two lateral and complementary organs in unity of action. But since the division of these median portions (§ 2049) or the removal of one of the cerebral hemispheres (§ 2053) does not destroy the mental powers, and since the median longitudinal section of the whole nervous centre in the frog does not disturb the simultaneous and corresponding action of the respiratory muscles (§ 2038), this theory must be regarded as on the whole invalid and incorrect.

2063. The organs of sight may best illustrate the actions which depend on the arrangement of the corresponding cerebral structures in pairs. We have seen that when two complementary colours are allowed to fall upon corresponding points (§ 1553) of both retinæ by means of the stereoscope, they produce the impression of white (§ 1564). Here we may imagine that the changes in the cerebral organs of the two optic nerves are completed to a single intermediate sensation in the brain itself. While the fact that the normal (and partially opposed) movement of gazing (§ 1445) is lost after injuries of one half of the corpora quadrigemina (§ 2045) or the cerebellum (2019)—suggests the conjecture, that the continuity of these lateral pairs is requisite for their combined action.

2064. We have already (§ 2029) represented the nervous centre under the guise of a row of keys, which are arranged suitably to their objects, and in fitting connection with each other. This forms a definite topography of structures, some of which represent the various organs of the body, while others minister to the purely cerebral functions. Such a view explains the apparent object of the reflex movements (§ 1955), as well as the real purpose of the instinctive actions. And it is confirmed by many of the phenomena of sensation.

2065. Although no sensuous impression can itself do more than furnish an excitement, the final translation of which must occur in the brain (§ 1905), still we always refer it externally: either to the peripheric organ, such as the tongue or skin; or still further outwards—for

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instance, to a corresponding distance from the retina or the optic nerve. Hence there must be some arrangement which obliges us to neglect our own cerebral actions, and to receive the peripheric transfer as though it were a direct impression.

2066. Under certain abnormal conditions, this external reference becomes sometimes very remarkable. Persons who have undergone amputation of a limb are good instances of this kind. A man whose thigh has been many years removed often distinctly feels his toes or foot. If the stump be surrounded with a ligature, the mutilated person feels as if the long lost foot and leg were asleep. Such deceptions can neither be overcome by the evidence of his senses, nor by his own consciousness of their error. And since they also occur in persons who have lost both legs, they are not due to the impressions applied to the existing limb being referred to that which has been removed. All of these sensations are far stronger in the hands and feet, than in the middle or proximal segments of the limb.

2067. Continuous pressure on the ulnar nerve at the elbow is attended by results allied to the preceding. The little finger first becomes "asleep," and then the ring finger and part of the middle finger; while subsequently the pain appears to run along the course of the nervous trunk. Similar pressure on the popliteal nerve gives rise to a pricking sensation in the toes and sole of the foot. And when the sciatic plexus of a parturient woman is compressed by the child's head, the impression of pain which is produced takes a peripheric course along her leg. Many unpleasant sensations in the alimentary canal and other peripheric parts of the body, depend solely on the nerves being affected either in the middle of their course, or in the centres themselves.

2068. The preceding considerations will show how slight are the foundations which physiology affords to psychology. One chief cause of this is certainly our deficient knowledge of the physiology of the nervous centre, a branch of the science which will probably never attain a very satisfactory position (§ 1927). But a second is the way in which we conceive of the mental functions. We describe certain external phenomena as results of knowledge, judgment, or reason, without recollecting that the basis here assumed to be an unit is the result of a series of links to which we have no access. We have seen that (§ 1708) the perception of the simplest sensuous impression, and the excitation of the slightest muscular movement, depend upon a transfer and conduction of certain material changes, which mutually conditionate each other, and play into one another like the cog-wheels of a machine. Hence we are justified in conjecturing, that what is apparently the most direct mental action also proceeds from a series of mutual tensions and transfers; and that the failure of any link of the chain leads to an error or a false conclusion. The general significance of such processes may

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be easily imagined from the analogies offered by these simpler phenomena. But the satisfactory investigation of their details—the only true self-knowledge—will probably for ever baffle the spirit of human inquiry.

2069. From hence alone it becomes obvious how far all phrenological systems are from the truth. Not one of the facts which constitute their foundation will survive a careful examination. The exterior of the skull is by no means an exact cast of that of the brain, but is modified by many intermediate conditions; such as the frontal sinuses, the thickness of the skull, and the form of its surfaces. And the outside of the brain is itself incapable of affording any conclusion as to the mental powers (§ 2059). If to these considerations we add, that the topographical subdivision of many of the phrenological organs is based upon misinterpreted facts of comparative anatomy, or absurd psychological subdivisions, and that external circumstances can materially alter the fatalism of the organic plan—the reader will clearly understand why physiologists are compelled to reject phrenology; and that only the more emphatically, the more violently it is defended by some educated persons.

2070. Numerous exact determinations of the size and weight of the skull and brain would probably furnish averages of some value for general psychology. Such cranioscopic researches have, on the whole, a more secure foundation than the theories of phrenology. But what has already been said renders it sufficiently obvious that it would still be quite impossible to determine, from such coarse material relations, the mental powers of any given individual.

2071. The restoration required by certain of the nervous organs leads to these phenomena of periodic rest which we include under the name of sleep. The time necessarily occupied by this strengthening inaction undergoes a great diminution in the course of life. The sucking child sleeps longer than it wakes. The adult is satisfied with about one-third of sleep, or even less.

2072. It is generally supposed that the whole of the nervous centre, or at least of the brain, rests during sleep. But more careful observation leads to the conclusion that this is not the case. It may even be questioned whether any part of the nervous centre is condemned to complete inactivity during sleep,—whether the whole phenomenon does not depend solely on the fact, that certain mutual actions, which occur during the waking state, are suspended in the sleeping animal.

2073. All the functions subservient to the metamorphosis of matter—such as the pulsation of the heart, and the circulation; the movements of respiration, and the interchange of gases; together with the mechanical and chemical phenomena which accompany digestion, absorption, secretion, and nutrition—go on unchecked during sleep. Hence certain parts of the medulla oblongata, and probably of the spinal cord, continue

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to act mechanically, just as in the waking state. And external irritations are capable of producing reflex phenomena without awakening the person. While, on the other hand, the occurrence of dreams teaches us that the brain is also in a peculiar state of activity. It perceives some sensuous impressions, but often gives them a different interpretation from what it would do in the waking condition. The ideas thus excited constitute the commencement of the most extraordinary phantasies, which as the dream goes on, are generally further spun out, and are repeatedly confounded with new and disconnected series of thoughts. All this indicates that the machinery of the nervous centre is differently adjusted in the sleeping and waking states. This alteration of adjustment causes many sensuous impressions to pass unnoticed, and many muscles of the body to become relaxed, while it allows others to execute the attitudes most favourable to repose. The peculiar changes of respiration which give rise to snoring are less essential (and therefore less constant) collateral effects of the same cause.

2074. Some observers have drawn a complete parallel between the condition of a sleeping animal, and one which has been deprived of its brain (§ 2055). But this comparison will not survive an exact analysis. The latter seems not to dream, and exhibits a peculiar irritability,—a somewhat unusual excitability to reflex (§ 1953) phenomena—which is not evinced by the sleeping animal. In short, that activity which sleep only diverts into another channel, is here altogether absent.

2075. The subjective phenomena of vision, and the fantastic images seen by many persons at the instant of falling asleep, are the immediate forerunners of dreams. The question whether these only occur just after the beginning and before the end of sleep, or during its whole continuance, cannot at present be decided. The statement that there are persons who have never dreamed rests upon very doubtful foundation.

2076. The sleeper instinctively executes many voluntary movements. Wearied soldiers have been known to sleep on a march, and still keep time in their steps. This fact plainly indicates that sleep is chiefly characterized by the isolation of consciousness from the impressions of the outer world, and not by the repose of the locomotive organs. We may verify the same proposition in the mysterious state of somnambulism: — which, in common with many other morbid conditions, proves that the keys of the nervous centre are capable of playing the most complicated movements, without the brain resuming its ordinary relations to the external world. The fact that a cataleptic person can maintain the arm until waking in the constrained attitude which has been artifically impressed upon it, shows that the continuous tension of the corresponding nervous organs does not always imply the influence of the will.

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2077. At present we are ignorant what material changes occur in the nervous centre during sleep. It has often been conjectured that the cerebral substance contains more dark blood than in the waking state. But even should this statement be hereafter confirmed, it will still remain doubtful whether the phenomenon is the cause of sleep, or the effect of a previous change in the bulk of the nervous tissues (§ 1990).

2078. The magnetic sleep, and animal magnetism generally, are some of the most equivocal phenomena which medical literature has hitherto offered to the thoughtful observer of nature. We may admit that persons suffering from nervous disorders are now and then susceptible to impressions which would pass unnoticed by a healthy individual; and that in such cases credulity, prejudice, implicit trust, and phantasy, can produce very strange results. Many nervous affections—such as the catalepsy already mentioned (§ 2076)—give rise to a variety of mysterious phenomena, which it will be long before physiology can explain. If it be true that these persons can maintain a limb in an artificial position which would soon exhaust a waking individual, or that the discourse interrupted by the attack is resumed by them immediately on its cessation (§ 1976),—this would exhibit a persistence in the mechanism of the nervous centre, due to causes concerning which nothing is known. But most of the wonderful phenomena generally described as results of animal magnetism depend upon conscious or unconscious deception. The whole of this subject forms a parallel to that of phrenology (§ 2069), an edifice which those who only work upon the foundations of natural laws have little call to aid in constructing.

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CHAPTER XIX.

GENERATION AND DEVELOPMENT.

2079. *Modes of Generation.*—Since natural inquiry, strictly so called, is only concerned with what may be established by experience, it has no right to discuss the question, how the first organic inhabitants of the globe were produced. The petrifactions which we meet with in various strata furnish us with a series of halting-points; from which we are justified in deducing the alteration of the several creations they represent, but not their original production. We are thus informed that the previous world was inhabited by species of animals which are now no longer met with; and that, myriads of years ago, what are now temperate zones were hotter climates, while existing continents occupied the depths of the sea. And palæontology and geology agree in indicating, that the organic beings of the globe did not proceed from any limited portion of its surface, or from any exclusive centre of creation, but that the varying geographical distribution of plants and animals is based upon a series of equally different local causes. But the way in which this happened, and the causes which permitted—or perhaps implied—the first organization, elude our present means of research.

2080. The same law which connects the life of every organized being with a certain duration of time necessitates the phenomena of propagation. Failing these, nature could only have avoided the depopulation of the globe by repeated new creations. Generation enables it to dispense with this requirement; which, as we shall see, is probably at present never fulfilled. Every organized being commences as an invisible germ, which continually attracts new substances, and by their proper elaboration, attains a certain stage of completeness. And when the development of the plant or animal has progressed to a certain degree, its organization acquires the capacity of producing, in some part of its substance, a new germ that exhibits the same capacity of development. Since the animal which thus results is immediately produced from the constituents of that by which it is generated, this mode of propagation has been called maternal or homogeneous generation. It is obvious that the time which must elapse before the new germination can possibly take place, will cause the producing animal to be older than the produced. Hence the former may arrive at its prescribed termination of life, at a period when the latter is still continuing a vigorous growth, and

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adding new links to the chain of creation. And thus, owing to the lapse of time which intervenes between the development of the previous germ, and the origin of the new one, it is only the individuals which pass from the stage of life:—the species of the organic beings are themselves permanent.

2081. Unfavourable external circumstances, and the predatory habits of various animals, cause many organic beings to perish before they reach that stage of development which enables them to prepare a germ. And many collateral causes may obstruct the evolution of the generative organs. The various dangers which thus threaten the maintenance of the species can only be obviated, either by one individual producing a number of germs simultaneously, or by its generative function being frequently repeated in the course of life. This also permits a gradual increase in the number of individuals which people the globe.

2082. In unisexual generation, the germ furnished by a single individual can at once go through its complete course of development. The bisexual generation, on the other hand, demands two different personalities. One of these, the female, furnishes the germ, which has generally a definite form, that of the ovum or egg. The second, or the male, prepares a special complementary fluid, which is called the semen or sperm.

2083. These two kinds of generative materials have their definite and special characteristics; which, subject to certain variations of form, are repeated in all animals. The annexed woodcuts represent the young ovum (Fig. 369 that of the pike, Fig. 370 that of the frog). It contains

FIG. 369.

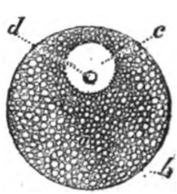
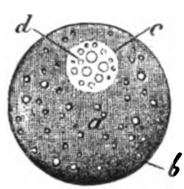


FIG. 370.



a basic substance or yolk *a*, which is enclosed in a special vitelline membrane *b;* a vesicular nucleus, the germinal vesicle, *c;* and one (*d*, Fig. 369) or more nucleoli (*d*, Fig. 370) that form the simple or compound germinal spot. The essential characteristic of the efficient male generative fluid is the possession of the seminal corpuscles (Tab. V. Fig. 78, *a b*), already specially described (§ 1215, *et seq.*).

2084. The ovum cannot spontaneously develope itself beyond a certain limited stage. In order that it should overstep this limit, and produce from its tissues the fœtus or embryo of the new being, it must have been previously subjected to the action of the male semen, or fecundated. Hence the bisexual generation to which the vertebrata are

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exclusively restricted, demands more elaborate antecedents in order to the production of a more complex and delicate organization.

2085. The higher animals just mentioned exhibit different sexes: many individuals possessing none but male organs of generation, which prepare and extrude the semen; while others have only female organs, which produce the ovum, and further develope it to a certain degree. The same arrangement is repeated in many invertebrate animals. But, on the other hand, in some of these lower animals, the same individual includes both male and female sexual organs. This genuine androgynous or hermaphrodite state is to some extent the expression of a low grade of organization. The organs of the higher animals work so peculiarly and exclusively, that they are only able to produce the material substrata of one of the two sexual contrasts: while the duller and more indifferent hermaphrodites can evolve both of the elements necessary to generation in separate secreting organs.

2086. The mammalian ovum only leaves the body of the mother when the fœtus produced in it is strong enough to maintain a separate life under the necessary collateral conditions. But since the action of the semen conditionates embryonal development, this must be preceded by an internal impregnation. The same conclusion holds good for other viviparous animals. The oviparous creatures offer two varieties in this respect. Birds, and most of the scaly reptiles, lay eggs which have previously undergone an internal fecundation. The evolution of their embryo is therefore entrusted to a mere external incubation, aided by favourable collateral circumstances. On the other hand, the ova of frogs and most of the osseous fishes are expelled before coming into contact with the semen. So that here the embryonal development, which takes place outside the mother's body, demands an external fertilization.

2087. The different modes of propagation which we have just been considering may be met with in various animals which are allied to each other. Although reptiles and fishes are, for the most part, oviparous, yet salamanders and sharks are viviparous. In the sword-fish and the *Marsupialia* the young undergo a further development in external brooding cavities or special pouches of the mother. But the arrangements of the two are very different.

2088. Unisexual generation obtains most extensively in the vegetable kingdom. Owing to the greater uniformity of their various groups of tissues, the more simple conditions of their nutrition, and the less complicated phenomena of their growth, the germinal structures which sooner or later shoot forth form independent plants; and pieces severed from the parent grow into distinct individuals. Their suckers and bulbs, their numerous buds properly so called, and the segments of their leaves and stalks, often possess the power of developing new shoots

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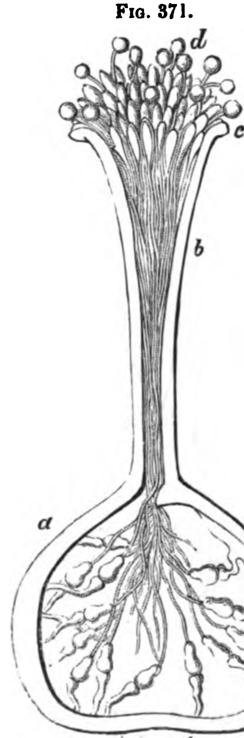
which maintain and increase the species. The operations of inoculation and grafting depend on the capacity for development possessed by severed portions of the leaves and axis. Here the maternal basis is so indifferent, that the plant into which the foreign portion has been grafted need only possess a certain degree of relationship, in order that the subsequent union of the two should allow of a more vigorous development, and the preparation of a richer sap. Finally, the weaker unity of the vegetable explains how severed portions of many cryptogamic plants continue to live uninjured, cellular projections from leaves or stems become perfect buds, and similar germinal structures proceed from the margins of wounds.

2089. We have already seen (§ 1222) that in many cryptogamic plants special organs—the ripe antheridia—enclose mobile elements, the forms and movements of which more or less correspond with those of the seminal corpuscles of the animal. Other organs produce seed-grains or spores, which subsequently yield young plants of the same species. This contrast, which may remind us of the bisexual generation of animals, is often met with in sea-weeds, leafy and fleshy mosses, and ferns. But at present the mechanism of their impregnation has not been discovered. Other modes of propagation are also met with in these plants, as well as in the higher vegetables.

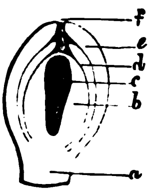
Fig. 371.



2090. The phanerogamous plants possess stamina, the anthers of which contain the grains of pollen; and pistils, which are continuous with the style and stigma, and enclose within their cavity the ovule or external basis of the future seed. The pollen grains (*d*, Fig. 371) subsequently gain the stigma (*c*); either spontaneously, or by the assistance of insects, winds, or changes in the position of the flowers. They remain sticking to the gummy covering of the style; and subsequently emit special prolongations, the pollen tubes. These contain the active mucous substance called the *fovilla* of the pollen grains. They gradually descend through the canal of the style (as shown in *b*, Fig. 371), gain the interior of the pistillary cavity, and betake themselves to the ova there present.

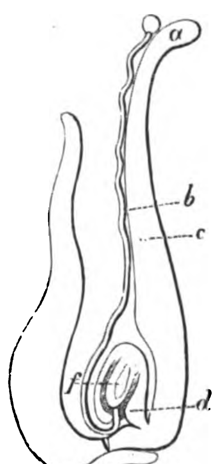
2091. The anther has long been regarded as the male, and the ovum as the female sexual apparatus of the phanerogamous plants. The fovilla, which would thus correspond to the male semen, often contains granules that exhibit the molecular movement discovered by Brown (§ 1188). But it possesses no elements having characters like those of the spermatozoa of cryptogamous plants or animals. The ova have an external membrane (*e*, Fig. 372), and a second internal protective sheath (*d*), to which are sometimes added other and similar structures. In the centre of all these lies a nucleus (*b*), in the substance of which is imbedded the embryonal sac (*c*). While the ovule attaches itself to the wall of the pistillary cavity (at *a*, Fig. 372), a canal (*f*) left by corresponding gaps in the membranes — the exostomium and endostomium—leads to the nucleus (*b*). The (generally elongated) embryonal sac forms a clear and transparent vesicle, which is filled with a peculiar solution. Still it cannot be compared with the germinal vesicle of (§ 2083) of the animal. For its want of a germinal spot, and its different subsequent development, prevent it from forming any satisfactory parallel with this important constituent of the animal ovum.

FIG. 372.



2092. There is no doubt that after the pollen-tube (*b*, Fig. 373) has passed from the stigma (*a*) through the canal of the style (*c*) into the pistillary cavity, it proceeds through the exostomium and endostomium to the nucleus. Schleiden states that this tube causes the embryonal sac (*f*) to be reflected on itself. New cells are then developed in its inferior extremity: they multiply, and gradually form the embryo. The radicle is subsequently directed upwards, and the attachment of the cotyledon buds downwards. In the mean time the upper portion of the pollen-tube gradually atrophies, and disappears. According to this account, it is the pollen which produces the most important part,—namely, that which at a later period of germination is developed into the new plant; the ovum only forming a suitable protective and nutrient mass, in which this is imbedded. This process would therefore constitute, not a bisexual generation, but only a special development from the pollen-tube of a bud, the further growth of which is assisted by its being properly implanted in the substance of the ovum. On the other hand, according to Amici, Mohl, and others, the lower end of the pollen tube does not enter the embryonal sac to be then metamorphosed into the embryo itself. The latter is produced independently, after the fertilizing fovilla has been

FIG. 373.



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conducted to the outside of the embryonal sac by the aid of the pollen-tubes. Hence the action of the fovilla on the internal structures of the germinal receptacle might to some extent resemble that of the animal semen on the unimpregnated ova.

2093. In the invertebrate animals, although, as a rule, generation is probably bisexual, even down to the polyps, still in numerous examples it is unisexual. Many of the circumstances here met with forcibly remind us of the methods by which multiplication is effected in the vegetable kingdom.

2094. Many animals in whom the whole body has a vegetative uniformity are capable of being multiplied by normal, accidental, or artificial divisions. Separate fragments of *Infusoria* (such as the *Paramœciæ*), of *Polyps* (such as the *Hydræ*), and of the *Trematoda* (such as the *Planariæ*), are frequently completed to form perfect animals. In many of the articulate worms—as the *Naiadæ*—transverse (but not longitudinal) division gives rise to the same result. Here we have what is, to a certain extent, the highest degree of reproductive capacity (§ 1062). This may, in some of the lower animals, assist to maintain the species; and will in any case diminish the injury of accidental attacks.

2095. Many infusory animals (such as the *Vorticellæ* or *Hydræ*), and some of the polyps (such as the *Corallinæ*), together with some of the *Helminthæ*—for instance the *Cystica*—often give out projections, which either only increase the number of animals in organic connection with each other, or subsequently fall off, and live as completely independent beings. But although these are called buds, still we must remember that it is only in their general mode of production, and not in their internal structure, that they resemble the bud of the plant.

2096. The fertilized ovum of a mammal or bird proceeds at once to the production of a developed animal. It is true that the constituents of the new creature undergo manifold changes. But we have always certain permanent characteristics, which more or less correspond with those of the adult animal. Frogs and salamanders exhibit greater differences. Here larvæ are first produced; these are devoid of extremities, and respire by gills, like most other aquatic animals. Subsequently the limbs gradually protrude; and ultimately, lungs replace the gills. The tadpole finally loses its tail, and assumes the shape of the developed frog. And in other animals we see far greater changes of form. Thus the butterfly has to pass through the preparatory stages of caterpillar and pupa:—while the Cirrhiped swims about as a marine crustacean, before acquiring its permanent form, and the attachment which condemns it to a sedentary life.

2097. That development of nursing-animals, which occurs in many of the invertebrata, and the circumstances of which have been so accurately elucidated by Steenstrup, frequently leads to a series of similar

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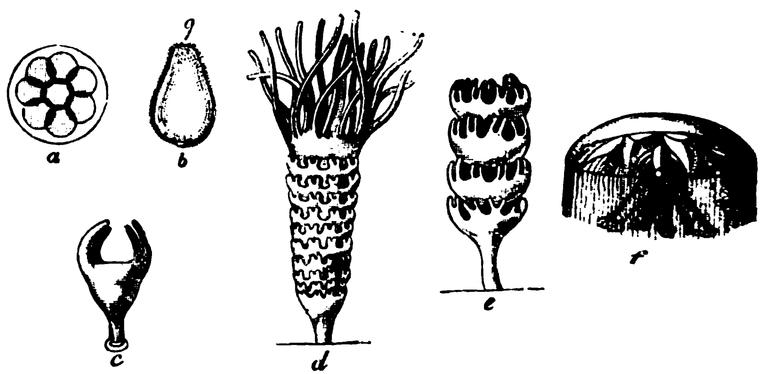
phenomena, as well as to many other peculiar effects. Thus instead of the new being proceeding at once along the path of development, it has to go through a prescribed succession of complex metamorphoses, before attaining the form and conditions of organization which obtain in the adult animal. And here, as in the simpler larval state, some of the organs at last become superfluous, and therefore disappear; while various important parts only sprout forth at a later period of development. But the two most remarkable phenomena we meet with are—that a single germ produces not merely an individual, but a series of animals; and that the latter are not produced directly by an ovum, although the original being from which they proceed is only formed under the influence of a bisexual generation.

2098. We have seen (§ 2085) that bisexual generation is but the visible sign of more delicate conditions of development. And the numerous circuitous routes which this generation by nurses often has to follow, may be regarded from a similar point of view. The accuracy of such a statement may be illustrated by some examples.

2099. The ovum of the *Medusæ* (or sea-jellies) first exhibits that peculiar fission (*a*, Fig. 374) which is often met with in other classes of

FIG. 374.



animals, and to which we shall return in considering the development of the embryo. According to the repeated observations of Siebold and Sars, it is then converted into a creature (*b*), which resembles one of the infusoria,—being provided with cilia (§ 1202), and capable of swimming about in the sea. This animal then becomes firmly attached to some other substance by its lower extremity, while the upper sprouts out into a constantly increasing number of branches (*c*). The whole is finally divided by a series of transverse sections, so as distinctly to resemble a set of cups placed one within another (*d*). Each segment now gives off processes (*e*); and then becoming completely separated, gradually developes itself to a perfect medusa (*f*). Hence we see that

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a single germ furnishes a series of individuals; and that each of these becomes a male or female, whose bisexual generation produces new germs which are destined to undergo the same development. So that the generation of these, and the cleavage of their progeny, play alternate and different parts; the first maintaining the species, the latter multiplying its numbers.

2100. Something similar to this is probably repeated in the *Salpæ* and *Tæniæ* or tapeworms. The young tapeworms—which are possibly produced from larvæ of a different form (Fig. 375), such as that called the *Tetrarhynchus*—change the form of their body, to give rise to the first links of their chain (*a*, Fig. 376). They then increase in length, and multiply their joints, either by division or interposition. Each of these finally gets the sexual organs and ova necessary to further propagation. The dark structures (*b*, Fig. 377) which are met with in the

FIG. 375.

FIG. 376.

FIG. 377.

mature pieces (*a*) of the *Bothriocephalus latus* indigenous in Poland, Switzerland, and Russia, are oviducts that contain many thousand eggs packed closely together. The joints are chiefly cast off at particular times of the year, such as summer; and are evacuated with the fæces, so as to allow the ova to undergo their further development out of the body. The rest of the head, which remains in the human alimentary canal, subsequently becomes elongated, and is then constricted so as to form new joints, which subsequently acquire sexual organs and ova.

2101. Just as a more or less perfect division is an essential link in this process, so in many polyps, there is a similar circuitous process of gemmation, which finally relapses into a sexual propagation. For example, the *Campanulariæ* shoot forth excrescences; which subse-

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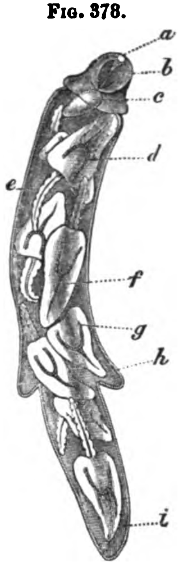
quently become free, swim about in the ocean, and only attain their sexual maturity after a certain period of development.

2102. A still more peculiar mode of multiplication, which may be called an endogenous generation, sometimes assists that by fission and external gemmation.

The young produced by the bisexual generation of some of the trematoid *Entozoa* at first swim free by means of their ciliated epithelium (§ 1202), and are subsequently converted into a peculiar vermiform animal. Now in many land- and water-snails, we find movable worms or living germ-tubes, which are probably produced by a similar metamorphosis. Such a tube is represented in Fig. 378, after a drawing by Steenstrup. Here *a b c* indicates the alimentary canal. In addition to this, the worm or nurse encloses in its interior a number of independent animals or *cercariæ*, *d*, *e*, *f*, *g*. These commence as a peculiar deposit, without any previous impregnation. They are developed within the mother; who serves as their cavity of incubation, and afterwards gradually perishes. They subsequently become free; and casting off their tails, bore into other animals, perhaps sometimes at once reaching their alimentary canal,—where they pass through a chrysalis state, and are finally metamorphosed into *Trematodes*, which further develope double sexual organs. It is probable that those female aphides which bring living young into the world are also mere nursing-animals; in which the new beings are produced from aggregations of cells.

FIG. 378.



2103. Hitherto we have only been occupied with the different forms of maternal generation. But it has also been imagined that living beings may be produced by the direct combination of the ultimate elements of their substance (§ 270), or from foreign and putrefying matters. This mode of origin has been named spontaneous, equivocal, or heterogeneous generation. Supposing such a process really obtained, it is obvious that new species, or at least new individuals, might at any time arise.

2104. The hypothesis of spontaneous generation was very favourably received in the infancy of science. It was then supposed that many of the lowest plants, and a large number of invertebrate animals, owed their immediate origin to putrefying organic substances; as did also some of the phanerogamous plants, and many species of vertebrate animals. But a more careful study of the phenomena of propagation subsequently proved that, in all the higher beings, the ordinary parental generation was the exclusive method; and that it even obtained in many lower animals, which were perhaps also producible by spontaneous

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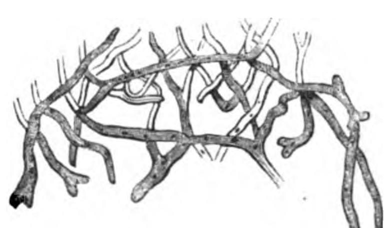
generation. And the further that the history of development was traced, the more the defenders of heterogeneous propagation were obliged to limit their hypothesis. So that, finally, the only instances in which it could be defended with any appearance of correctness were those of the mould-plants, *Confervæ*, and *Infusoria*, that appear in putrefying liquids; together with the various parasites, and the seminal corpuscles which were then regarded as genuine animalcules.

2105. A careful examination must withdraw even these last supports from the doctrine of non-parental propagation. The seeds of the mould-plant and the *Algæ*, as well as the germs of infusory animalcules, are so minute and light, that they are propelled to a great distance by the weakest currents of air or water. A few threads of mould frequently deposit thousands of spores. Hence a great number of the latter may be lost without endangering the maintenance of the species. Should some of these accidentally find a suitable *nidus*, numerous masses of mould can grow in a very short time. And experience teaches that many of these plants flourish luxuriantly in dilute acids. Hence that acid fermentation (§ 324) to which organic substances are so liable during their spontaneous decomposition, yields a favourable nidus for the development of any spore-granules which may accidentally have reached it. This character of the nidus and the food explains why mould-plants are found in the relics of digestion (§ 496), and why the scabs of cutaneous eruptions show enormous quantities of mould-filaments under the microscope. The annexed figure (Fig. 379) represents those which occur in the crusts of the scalled heads of children.

FIG. 379.



2106. The lower or polygastric *Infusoria* present similar phenomena. Their germs and young are of such small size, that they easily penetrate invisible apertures. The facility with which they multiply is favoured by the peculiarities of the sarcode (§ 1224) which constitutes the bulk of their corporeal substance.

2107. We may convince ourselves by experiment that these living creatures do really enter infusions from without. If distilled water be boiled for some time, and sprinkled with fragments of a plant or an animal while it is yet hot, and if the whole be now hermetically sealed, so as not to leave any air over the liquid, no mould-plants or infusoria will be developed. The continuous boiling of the water killed the germs of the minute beings which it probably contained. And supposing none to have been present in the organic matters exposed to putrefaction,

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their subsequent absence is also explained. And a certain quantity of air which has been just passed through a solution of potash, may be allowed to stand over the fluid infusion, without the appearance of any *Infusoria*. But there are obvious reasons why the presence of the ordinary atmosphere should lead to the development of these animals, as well as of the mould-plants.

2108. The rapid growth and great multiplication of these minute organisms, when received into a suitable locality, will explain many of the phenomena of contagion which are so often met with in the vegetable and animal kingdoms. If a small quantity of the mould that occupies apples or pears be transferred to a puncture in a sound fruit of the same kind, this often becomes mouldy after some time. That most destructive disease of silk-worms, called the *muscardine*, consists in the growth of mould within the abdominal cavity of the insect;—a growth which sooner or later kills it. Here again a healthy individual may be infected by an artificial transfer. The same result may sometimes be brought about by inoculating them with the vegetable parasite of the scalled head, or with other vegetable parasites of the human body. In this way infection may be voluntarily produced, even with the coarse material aids at our disposal.

2109. The *Rotifera*, which are closely related in structure to the *Annulata*, propagate by means of ova. Some of these creatures can produce many generations in the course of a few hours. This explains why we sometimes find vast numbers of them in a small quantity of water which has only been taken out of a pool the day before, and which perhaps contained but a single parent individual.

2110. Many of these *Rotifera*, as well as the Tardigrade animalcules which exist in the gutters of roofs, enjoy an advantage unknown to most other beings. They may be completely dried up, and subsequently soaked in water, without losing their capacity of life during this important change of state. They may thus be preserved for years without moisture. A drop of water soon restores them to their original activity. Higher degrees of heat generally destroy the vital capacity of the various animal and vegetable tissues. But such a dried-up Tardigrade may be exposed to the temperature of boiling water without the application of fluid, and still, according to Doyère, live when moistened. When boiled in water, however, it dies like any other animal. This difference reminds us of the relations of fluid albumen; which, when mixed with or dissolved in water, coagulates by heat, while when completely dried, it is capable of supporting a higher temperature without losing its solubility.

2111. The notion of a spontaneous generation derives its strongest apparent support from the external parasites (*Epizoa*), and from the intestinal worms which occupy the interior of the body (*Entozoa*). The

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occurrence of Cystic entozoa (*Cysticercus*, *Cœnurus*) in the brain and areolar tissue, of *Distomæ* in the liver, of *Strongyli* in the kidneys, and of *Trichinæ* in the muscles,—appeared to be best explained by the supposition that they originated directly from the decomposed juices of the body. But the various intestinal worms—the *Ascaris*, *Oxyuris*, *Trichocephalus*, and the tape-worms (*Tœnia* and *Bothriocephalus*)—rather countenance the supposition that they penetrate from without; either alone, or mixed with food. Formerly, however, it was almost universally believed that the intestinal worms could only live within another organized being. Hence the more accurate opinion was either rejected or passed over in silence.

2112. Here again recent observations have deprived the hypothesis of spontaneous generation of all its probability. They have distinctly proved that these animals originate from a bisexual generation, and often have to pass through a series of remarkable conditions—either as larvæ or nurses (§ 2099)—before attaining their final form, and with it, their capacity for sexual propagation. In these states, they frequently live free and devoid of all organic nidus. Thus the ova or young leave the animal at a definite time, and, subsequently, when their stage of development again requires them to resort to a living animal, seek to return either to it or a similar one. Here a series of periodical changes, and many remarkable circuits, all conduct to the same final result:—namely, that such creatures occupy the innermost recesses of another animal. This may be best illustrated by some examples.

2113. The number of germs generally increases in proportion to the dangers which oppose their development (§ 2081). On this account fishes and frogs have vast numbers of eggs, a large portion of which perish without attaining their object. And since the incubation of most of the intestinal worms is exposed to innumerable accidents, the same provision is also repeated in these parasites on a very extensive scale.

For example, Fig. 380 shows the chief internal organs of a *Filaria* or thread-worm, from a fish, the *Trigla*. Here the long oviduct *c* winds along the greater part of the intestine *b*. The similar oviduct of the ascaris makes still more numerous curves, and is so distended with minute ova, that a single female contains many thousands of germs. Each of the older joints of the *Bothriocephalus latus* (*a*, Fig. 377, p. 615) possesses a female sexual apparatus, which encloses at least many hundreds, and probably many thousands, of eggs. According to Eschricht, the different joints from time to time given off by such a tape-worm together amount to 10,000. So that a single animal can gradually develope many millions of ova.

2114. The young of many intestinal worms are developed in the interior of the animal which the parent inhabits. Indeed many *Hel-*

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FIG. 380.

minthæ belong to the class of viviparous animals (§ 2086). But the ova or young of others appear to be only capable of thriving out of the body. Although the adult *Ascaris*, *Oxyuris*, and *Trichocephalus* (§ 2111) are often found in the human intestine, their developed ova have never been detected in this situation. The heads of the *Tæniæ* produce new joints by prolongation and subsequent transverse division (§ 2100). When the several joints have reached a certain stage of development, they acquire sexual organs, in which ova are produced and developed to a certain degree. These having arrived at maturity, a segment of the tapeworm becomes spontaneously detached, and is evacuated in the fæces. This exit of headless portions, which is really due to the normal course of development, might easily be attributed to any medicaments that may have been made use of. But the head still left in the intestine possesses the capacity of again producing new joints.

2115. The experiments instituted by Eschricht plainly indicate a certain periodicity, such as is often betrayed by the human *Bothriocephalus* (§ 2100). A fish of the Baltic Sea (the *Cottus scorpio*) contains a tapeworm (the *Bothriocephalus punctatus*) whose head grows new joints in autumn and the beginning of winter. The ova these contain attain maturity in the course of the spring. The joints in which they are imbedded (§ 2100) are then detached, and expelled with the fæces. Hence in the summer the fish contains none but neuter or unisexual parasites. The ova expelled with the fæces are probably set free by the gradual putrefaction of the surrounding substance of the joint:—to be afterwards developed into larvæ, the evolution of which continues until they can again take up their final residence in a similar fish.

2116. Circumstances connected with their

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nutrition or growth frequently induce the entozoa to change their residence. Such circumstances may be either accidental, or due to causes essentially final. The *Lumbrici* frequently wander out of the rectum into the vagina. They may also migrate from one child to another. And just as many granivorous birds eat indigestible seeds, in order that these may be deposited with their fæces at a distant place—the animal thus forming a living means of transport—so many intestinal worms can only undergo a complete development after the voracity of another animal has transferred them to a more favourable nidus. The intestine of the stickleback (*Gasterosteus*) contains a tapeworm (the *Bothriocephalus solidus*), which here developes no sexual organs (§ 2100). But if its landlord is accidentally devoured by an aquatic bird (such as one of the divers), the parasite, which resists the solvent powers of its digestive organs, gains a dwelling more favourable to its further development. Its joints then develope mature ova in their female sexual organs, giving rise to what seems a new species of tapeworm (the *Bothriocephalus nodosus*). These ova are subsequently discharged from the bird's body; so that the resulting worms, when developed to a certain degree, can again seek out a stickleback as their preliminary residence.

2117. The wanderings which appear to constitute an important element in the life of most entozoa often require special locomotive organs or offensive weapons, by which the animal attains its new residence. Hence many of their embryos and young have a ciliated external surface (§ 1202). Others possess hooks, prickles, and similar horny structures, by means of which they are enabled to bore into the interior of various animals. When this object is completely attained, these weapons often perish, or are converted into other structures more suitable to the period — for example, into suctorial organs, which facilitate the absorption of the juices of the being that now serves as their residence.

2118. While the intestinal worms were formerly often looked upon as condemned for life to a definite and concealed habitation, later researches agree in indicating that most (if not all) parasitic animals spend a considerable part of their life in travelling. In some instances, Nature seems compelled to make use of every means which can possibly conduce to this end.

2119. The food often serves as a means of smuggling in the intestinal worms, and their eggs or larvæ. Small animals akin to the vinegar-eel (*Anguillula aceti*) exist in mildewed corn, and in the seeds of similar grasses. They possess an extraordinary tenacity of life, being not even destroyed by desiccation (§ 2110). Siebold offers the justifiable conjecture, that they are early stages in the development of other *Helminthæ;* and that when such grain is eaten, they can undergo a further development in the intestine. It is probable that aquatic animals often consume joints of tænia, or the ova and young of various parasites, along with the

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food which is so easily contaminated in their haunts. And we shall scarcely go too far if we deduce the production (or rather the transfer) of the tapeworm in particular localities mainly from the use of certain waters.

2120. The movement of the blood may also assist in forwarding the younger entozoa toward their destination. Sometimes many of the vessels of a frog contain small creatures resembling *Filariæ* (§ 2113). In examining the circulation of the web, these may even be seen propelled with the blood of the capillaries (§ 651). Similar creatures are often contained in the membranes of pupæ which are imbedded in the walls of the stomach and intestines. But, on the other hand, they often occupy very concealed places;—such as, for instance, the neighbourhood of the choroid plexus of the fourth cerebral ventricle (at *E F*, Fig. 368, p. 589). It is probable that the pointed extremities of their bodies endow them with a power of penetrating the walls of the blood-vessels, and of subsequently leaving the current of blood at some distant part of the body.

2121. In fishes, the entozoa which seek to advance by such powerful mechanical means have been observed projecting from the intestines, muscles, or skin. The sand-flea (*Pulex penetrans*) of the torrid zone of Brazil thus nestles in the naked human foot. The *Filaria medinensis* probably penetrates in the same way, either in the adult state or at an earlier period of its development. We have already (§ 2102) seen that the cercariæ of the *Distoma* bore into the bodies of other animals, and are here metamorphosed into more perfect intestinal worms. The development of nurses (§ 2097), and the endogenous mode of generation (§ 2102), has also been noticed as sometimes occurring in the Helminthoid class.

2122. The external obstacles to the wanderings prescribed to the entozoa frequently lead them into by-paths, the results of which are seen in various ways. No doubt a large portion of the eggs or young perish for want of the nidus necessary to their further development. The immense number of such germs (§ 2113) is thus explained. But it may also happen that, in a less suitable residence, these creatures degenerate, and are gradually converted into peculiar animals.

2123. According to Siebold, it is probable that when the young of a certain tapeworm (*Tænia crassicollis*) found in the cat stray into the body of a rat or mouse, they become dropsical. If they penetrate the liver, they retain only the anterior half of their body, and are found enclosed in a cyst. And when a cat devours the mouse inhabited by the parasite, the latter, if it have not suffered too much, may possibly resume its normal course of development. Thus Siebold conjectures that the hair-worm (*Trichina spiralis*) sometimes found in thousands within the striped muscular fibres of men or animals, is nothing more than the larva

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of some other parasitic animal; which has lost its way, and has therefore become crippled and sexless.

2124. From all this it is evident, that the two chief grounds on which it was thought necessary to assume the spontaneous generation of entozoa—viz. their apparently residing exclusively within other animals, and their occurrence in the most concealed recesses of the organism—will, in the present state of our knowledge, no longer sustain this theory. We now know that the entozoa either can or must spend one part of their lives in a state of freedom, and another within various animals. These migrations, and the organs by which they are aided, will also explain the presence of such animals in the most secret organs of the body. Besides, all that has hitherto been observed expressly indicates, that there is no departure here from the general rule of parental generation—nay, for the most part, not even from the rule of bisexual propagation. Only circumstances often compel the adoption of very roundabout methods for the production of those beings which develope the semen, the ova, or both.

2125. The fact that the entozoa are developed by a parental mode of generation exercises a certain influence on the pathology of the complaint which their presence produces. It renders this *helminthiasis* a disease produced by contagion; while the notion of the spontaneous generation of entozoa stamped it as a simple *dyscrasia*. We may indeed admit that a faulty admixture of the juices can perhaps favour the prosperity of many parasitic animals. But since these must always be introduced from without, any improvement in the elaboration of the juices could at most only prevent the proper development or maintenance of the individuals themselves. Besides, few of the entozoa produce any remarkable phenomena of disease. Some of them, as the *Filaria medinensis*, lead to the formation of ulcers. Tape-worms sometimes give rise to colic of variable severity. But many of the symptoms assigned to worms in medical treatises are not really due to the influence of these parasites.

2126. We shall hereafter see that the gradual development of spermatozoa (§ 1215) in the interior of cells may be directly followed under the microscope. Could we regard these bodies as animals, and not as tissues, they would form the strongest arguments in favour of the possibility of spontaneous generation. The assumption of their animal nature was mainly founded upon the movements which they generally exhibit at the period of their maturity (§ 1217). But the spermatic elements of many entozoa and crustaceans appear to be devoid of the capacity of movement. Besides, so far as we know, every animal can reproduce its like, so as to assist in maintaining its own species; while nothing at all akin to such a propagation is seen in the mobile seminal corpuscle. Finally, by classifying the spermatozoid among the tissues

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we shall be better able to conceive, why similar structures occur on the cutaneous surface of some polyps (§ 1223),—and why the *Psorospermia* met with by J. Mueller in many tumours (*e.g.* of fishes) possess a considerable resemblance to seminal corpuscles, although devoid of all trace of movement.

2127. On the whole, the hypothesis of a spontaneous generation of plants or animals can only be regarded as a kind of superstition, which is constantly receding before the advance of the natural sciences. All experience concurs to indicate that species are at present only maintained, without any new ones being created. Their original creation would perhaps demand conditions and meteorological states different from those attainable at the present day. Unfavourable collateral causes have totally destroyed some species — such as the Dodo — in the last few centuries.

2128. That parental generation which is alone evident to our senses may occur in a variety of ways, according to the special circumstances of different organizations. Reproduction by fission or division is based upon a close correspondence between the various segments of the existing corporeal mass. Gemmation and endogenous generation are connected with an easy deposit of the first rudiments of the new being. While sexual propagation implies the most delicate conditions of growth. The sexual organs may themselves also be formed either directly or indirectly. The more homogeneous young of many of the lower animals have not acquired the capacity of producing special sexual products. Hence the evolution of the specific sexual organs may be preceded by various intervening stages; such as those of fission, gemmation, endogenous generation, and the various and mysterious kinds of growth and propagation that are connected with the formation of nurses. Finally a lower degree of organization permits of hermaphrodism; and a higher one effects the separation of the sexes.

2129. *Male sexual organs.* The chief object of these organs consists in the preparation and expulsion of the semen, which is provided with moving seminal corpuscles. The seminal matter of man and mammals originates in the tortuous seminal tubes which fill the various lobules of the testicles (*s*, Fig. 382, p. 625). It then passes through the *rete testis*, the *vasa efferentia*, and the *coni vasculosi*, towards the *epididymis* (*t*) and *vas deferens* or seminal duct (*v*, *w*, *p*, *q*), undergoing in the meantime a further development. Hence, under favourable circumstances, the whole development of the seminal elements may be followed in the organs of the same individual.

2130. When a person has attained the age of puberty, he acquires the capacity of secreting a fertilizing semen at all periods,—a capacity which he retains until extreme old age. Animals, however, only become ruttish at definite epochs. They then fall into a condition of increased

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sexual excitement. The bulk of the testicles is more or less increased, and they yield mature semen; while at other times, they are either completely at rest, or only prepare smaller quantities of a somewhat different fluid. Here again the period of rut only occurs after the attainment of a certain age. When this period has passed, no new spermatozoa are formed, and the residue of the old gradually disappear.

2131. The testicles of the human subject secrete more slowly than most of the other glands. A rapid succession of excitements and evacuations may spur them on to a somewhat increased activity. But since the complete development of seminal elements demands long periods of time, the fertilizing fluid evacuated under such circumstances exhibits under the microscope a constantly diminishing number of free and moving seminal corpuscles, and a corresponding increase of those in the earlier stages of development.

2132. In all the animals which have hitherto been examined the spermatozoa are developed in cells, by the destruction of which they are subsequently set free. We first observe small, simple, and roundish cells (Tab. V., Fig. 78, *c*), in which we afterwards perceive some separate secondary masses, or complete secondary cells (Tab. V., Fig. 78, *d*). The latter form the materials for the development of the spermatozoa, which lie either separately (*c*, Fig. 200, p. 363) or in bundles (Fig. 381) within the parent cell. The walls of the parent cell are finally dissolved, so that the spermatozoa move freely about in the seminal fluid (Tab. V., Fig. 78, *a b*).

FIG. 381.

2133. In the mature semen of man and most animals, there is scarcely anything mixed with the *liquor seminis* save the moving seminal filaments. This fact may be sometimes verified with the contents of the vas deferens (*v*, *w*, *p*, *q*, Fig. 382) and epididymis (*t*) in the bodies of chaste men. But the substance met with in the tubules of the testicle contains younger cell-forms, which are mechanically admixed with the fertilizing fluid. Loose epithelial cells, and a few scattered oil-drops, may also be present. And where the seminal evacuations succeed each other too rapidly, large quantities of the semen-cells are found in the emissions.

2134. Hitherto the quantitative composition of the pure seminal substance has not been accurately determined. According to Frerichs, the fluid which surrounds the immature seminal corpuscles contains albumen, while the mature fluid contains horny substance. The development of the spermatozoa may therefore be compared to the process by which the cuticle becomes horny (§ 1016).

2135. The emission of semen is generally due to a reflex action. Friction of the glans (*f*, Fig. 382) gives rise to reflex movements in the vasa deferentia (*v*, *w*, *p*, *q*,) and probably also in the seminal tubules of the epididymis (*t*) and testicles (*s o*). This effect may be artificially pro-

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duced in recently killed animals. The semen next reaches the inferior and glandular part of the vas deferens (*r*, Fig. 382 ; *f*, *g*, Fig. 383). It then traverses the urethra (*z a′ b′ d′*, Fig. 382) to gain the orifice of the glans (*g*, Fig. 382): whence it is ejaculated with a force which, in vigorous men, can expel it to a distance of many feet.

FIG. 382.

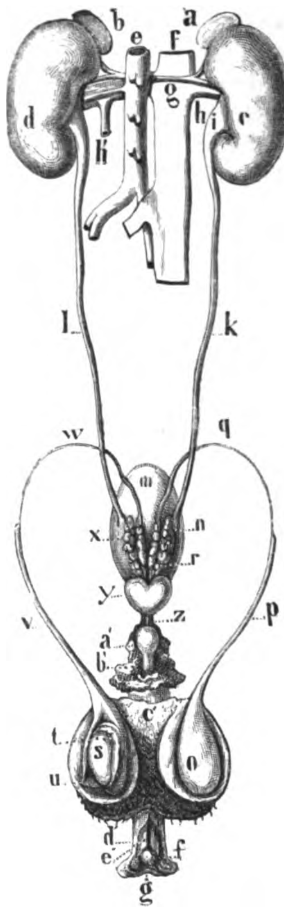
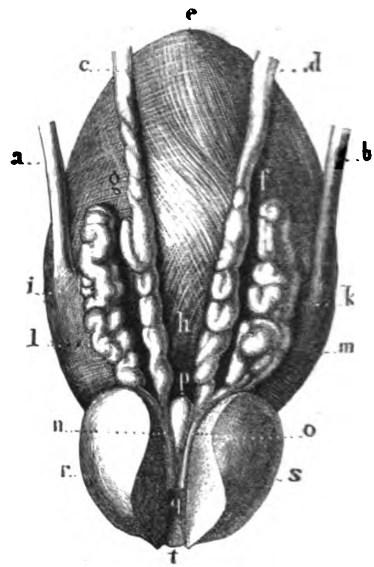


FIG. 383.



2136. Sometimes a direct irritation of the nerves also leads to seminal emissions. In recently killed mammalia, mechanical or chemical irritation of the lumbar portion of the sympathetic has been observed to produce such violent contractions of the vesiculæ seminales as to cause the expulsion of semen from the orifice of the urethra. The urethra of beheaded criminals contains a mucous fluid, in which spermatozoa may be recognized under the microscope. The emission of semen was formerly believed to be characteristic of death by hanging. But it does not always occur; and is probably limited to those cases in which the upper part of the spinal cord has been much injured.

2137. The tubular and glandular *vesiculæ seminales* (*l*, *m*, Fig. 383; *x*, Fig. 382) contain a mucous fluid, in which seminal corpuscles may sometimes be met with. They furnish a peculiar secretion, which is only now and then mixed with true semen. Hence they are not the necessary receptacles of the fertilizing fluid; and thus enact a part very

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different from the gall-bladder (§ 923), and the urinary bladder (§ 938), with respect to the bile and urine.

2138. Each of the vesiculæ seminales (*l m*, Fig. 383) unites with the corresponding vas deferens (*f g*) to form a short duct (*n o*), which opens into the urethra on the *verumontanum*. In the annexed figure (Fig. 384) *a* represents the ureter (*k*, *l*, Fig. 382; *a*, *b*, Fig. 383), *c* the vas deferens, and *b* the bladder (*m*, Fig. 382 and *e h*, Fig. 383) which has been slit up, and is continuous with the similarly exposed urethra; while *d* indicates the aperture of the ejaculatory duct of the semen. But since the vesiculæ seminales contract simultaneously with the vasa deferentia (§ 2135), it is not pure semen which enters the urethra, but a mixture of this substance with the secretion of the vesiculæ (§ 2137) themselves. It is probable that the prostate gland (*e*, Fig. 384; *r s*, Fig. 383; *y*, Fig. 382) at the same time empties its fluid secretion into the neighbouring part of the urethra (above *d*, Fig. 384). Further onwards Cowper's glands (*g*, Fig. 384) also pour out their contents. The semen is thus mixed with a number of foreign constituents. The resulting mixture of secretions deposits flocculi in the open air. It stiffens linen on which it dries, and communicates to it a faint greenish-grey colour.

FIG. 384.

2139. Although the urethra is the common efferent canal of the urine and semen, still, under normal circumstances, the two secretions

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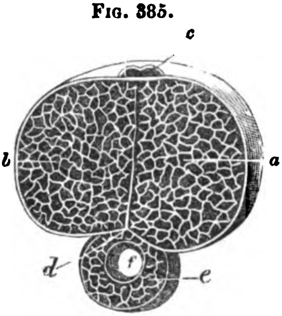
are never expelled simultaneously. The bladder remains closed at the instant of emission (§ 942). And we shall see that the erection of the penis materially assists to shut off the bladder from the urethra. And conversely, the mechanism which expels the urine (§ 941) leaves the seminal ducts and vesicles undisturbed, so that no ejaculation then takes place. But in persons who suffer from diseased spine, or are addicted to onanism or sexual excesses, the semen is often discharged involuntarily at the end of micturition, without any voluptuous sensation. This spermatorrhœa is by no means so dangerous as it is generally supposed to be. And if such persons sometimes become hypochondriacal or paralytic, or even die of emaciation, it is not from the losses of substance caused by these seminal emissions, but from the collateral nervous disturbances which sooner or later ensue.

2140. The erection of the penis is not a necessary antecedent of seminal emission, but is chiefly subservient to coition, by enabling the organ to distend the tube of the vagina more completely, and thus to excite more intense voluptuous feelings in both sexes. And since it only requires the presence of the trabecular or cavernous tissue which we shall shortly describe, it often occurs without any such object — for example, in new-born infants. And eunuchs, or men who have lost a portion of the penis, are still capable of more or less complete priapism.

2141. The annexed woodcut (Fig. 385) represents a transverse section of the upper part of an adult human penis, which has been inflated from the veins, and then dried. The two *corpora cavernosa* — *a* and *b* — are separated from each other by an aponeurotic partition *c d*. They form the erectile or trabecular tissue of the penis. They finally fuse into each other, and terminate by becoming continuous with the erectile tissue of the glans. At *e* is the *corpus spongiosum* of the urethra *f*. In Fig. 384 part of the fibrous network is seen in longitudinal section.

FIG. 385.



2142. The corpora cavernosa result from an intimate union of numerous veins, the cavities of which thus form the meshes of a many-sided network. Hence we have here, as it were, the greatest possible concentration of anastomosis; — the most perfect *rete mirabile* of the whole venous system. The broader partitions which divide the several cavities enclose afferent arterial trunks; as do also the smaller trabeculæ which often traverse the larger ones. Many of the finer of these vessels take a spiral or tortuous course; this is especially the case with those contained in the smallest partitions. These then continue directly into the adjoining venous cavities, without the intervention of any capillary network. While, on the other hand, the broader partitions—which form

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part of the root of the organ, and the whole of the remaining trabecular tissue—contain reticulate vessels, that are subsequently continued into the venous cavities. The arteries nowhere terminate by blind extremities. Those called the *arteriæ helicinæ*, and which have been supposed to end in this way, are only twigs that have been torn off and then coiled up by their own elasticity: prior to this they occupied the smaller trabeculæ, and were cut across in some part of their course by division of the corpus spongiosum. In addition to these vessels, the numerous partitions contain white and yellow fibrous tissue, unstriped muscular fibres, nerves, and probably absorbents. Their external limitary surface is formed by the internal coat of the veins.

2143. Erection of the penis is not always due to that sexual excitement which forms its most appropriate cause; but may be produced by mechanical irritation—especially friction of the glans,—by pressure on the nerves of the penis from a distended bladder, calculi, or tumours; and by irritation of the nervous centre. After its bulk has increased to a certain extent, voluptuous feelings are generally superadded.

2144. All the external changes exhibited by the penis in a state of complete erection—namely, its increased volume and hardness, and its direction upwards—depend solely on extreme distention of the meshes of its erectile tissue. Thus, in the dead subject, the imitation of this distention by injection produces a state of complete erection. But the two chief causes of this change of circulation have not yet been satisfactorily determined. We are ignorant in what way the nerves of the penis permit the afflux of more blood to the cavernous tissues. And we can but imperfectly explain, why most or all of the fluid thus brought is retained in their meshes.

2145. The root of the penis first enlarges in volume (below *g*, Fig. 384, p. 627). The increase of bulk then advances towards the glans. Erection and hardening only occur after a certain amount of distention. Since the channel formed by the venous intervals of the fibrous network is considerably larger than that of the afferent arteries, it is obvious that the blood will traverse these cavities with a diminished velocity, and be retained in them for a longer time (§ 106). But this fact will at most only explain why the erectile tissues of the relaxed penis should contain large quantities of dark blood in the state of rest. While that excessive distention which causes erection implies that there is some decided obstacle to the expulsion of the venous blood, the afflux of the arterial fluid remaining free. Since the arteries are protected by their running in the interior, the continuance of their afferent stream is easily explained. And as regards the return of the venous blood, it has been supposed that special muscles (the *ischio-cavernosi*) compress the penis against the symphysis pubis (below *k*, Fig. 231, p. 394), and thus close the efferent venous trunks. But there is a second theory, which

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seems more in correspondence with the truth — namely, that the exit of blood is opposed or altogether prevented by part of the unstriped fibres which occupy the septa.

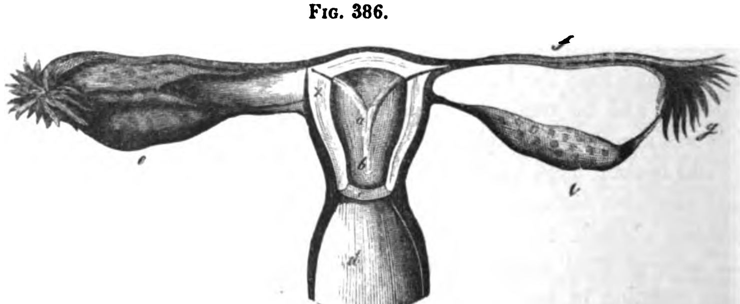
2146. After the seminal emission, the erection of the penis soon diminishes. The return of the organ to its normal bulk occupies less time than its previous erection. The sluices of the venous blood are now suddenly opened. The elastic reaction of the immoderately distended partitions and membranes presses upon the blood in contact with them. The unstriped muscular fibres (§ 2142) probably add to this propulsive force. The excess of blood is therefore returned with increased velocity from the spongy texture towards the pelvic veins.

2147. When the nervous discharge which generally accompanies seminal emission does not occur, the erection disappears much more slowly. The tissues which hinder the return of the blood then yield but very gradually. And nervous influences can subsequently produce a second erection with greater ease and rapidity.

2148. The visible increase in the bulk of the penis is chiefly due to the spongy tissues of the glans (g', Fig. 382, p. 626) and urethra (c). Their interspaces communicate (a b, Fig. 385, p. 628) with each other, and thus under all circumstances secure the perfect access of the blood. Other venous cavities extend along the bulb (a', Fig. 382) and the constricted portion (z) of the urethra, as far as to the neck of the bladder (from g to e, Fig. 384, p. 627). These likewise swell, and thus secure the perfect closure of the vesical orifice. Hence a man who wakes with a complete erection of the penis can only micturate after it has to some extent subsided.

2149. *Female sexual organs.* While the testicles furnish the male fertilizing fluid, the ovum which constitutes the essential female generative products is produced in the ovary (e, Fig. 386). The Fallo-

FIG. 386.



pian tube or oviduct ($g\,f$), and the uterus (a b) into which this subsequently opens, only add new structures to protect and nourish it after impregnation. In many of the lower animals the ovary is essentially

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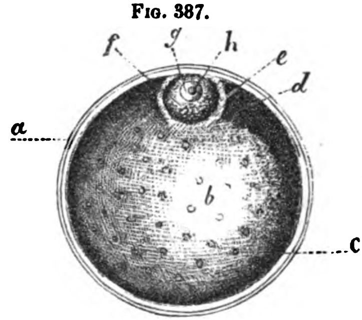
a tubular gland (§ 857), which contains ova or peculiar cells as the secretion of its tubes. But the mature ovary of the mammal appears, at first sight devoid of all traces of glandular structure.

2150. While the ovarian ova of birds, amphibia, fishes, and many invertebrata, are enclosed in thin capsules, those of the mammalia present a more complicated organization. They contain a certain number of vesicles, the Graafian vesicles or follicles, which project from the surface of the ovary, so as to elevate its peritoneal covering, and are imbedded by their remaining portions in its substance or stroma. Each of them includes a single minute ovum. In rare instances, two or more are present.

2151. The annexed diagram (Fig. 387) represents a section of a Graafian vesicle from the human ovary. At *a* is the follicular membrane which everywhere encloses it. A peculiar homogeneous fluid fills up the greatest part of its cavity *b*. Almost all the inner surface of the follicular membrane *a* is covered by a proper *membrana granulosa c*,—the roundish cellular or nuclear elements of which are imbedded in a homogeneous gelatinous substance, and are at first arranged in the form of a tesselated pavement. The extremely minute ovum *f g h* occupies the highest point of the follicular cavity. It is everywhere surrounded by a clear ring or girdle *e* called the *zona pellucida*. Many regard this as a substitute for the vitelline membrane (§ 2083), while others state that there is a special vitelline membrane in addition to this. The *discus proligerus d* arises from a thickening and projection of the membrana granulosa in the neighbourhood of the zone *e*. Its innermost and thickest section forms the *cumulus*. The ovum itself contains the yolk or *vitellus f*, the germinal vesicle *g*, and the germinal spot *h* (§ 2083).

FIG. 387.



2152. We have seen (§ 2130) that it is at the period of puberty or sexual maturity that the testicles are first endowed with the capacity of developing a true semen provided with spermatozoa. But Graafian vesicles and ova may be met with in new-born infants, and even in the advanced embryo. It has often been conjectured that in course of time the older vesicles are absorbed, and new ones developed in their place. But hitherto this statement has not been fully established.

2153. The ova of birds and the other lower vertebrata undergo more or less enlargement prior to their exit from the ovary. But those of the mammalia leave their original habitation as structures of extremely minute size. A special mechanism effects this change of their residence.

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2154. The larger and riper follicles project from the surface of the ovary. The vessels which surround the follicular membrane (*a* Fig. 387) of the vesicle that is about to burst become greatly distended with blood. This considerably increases the quantity of its contents *b*, and the distention of the whole follicle. A quantity of blood is sometimes effused into the cavity of the vesicle, where it subsequently coagulates. To this is always added an exsudation, which is at first deposited at the bottom of the vesicle (*c*), without completely filling its uppermost part (*a*). The fluid contents of the follicle are hence impelled towards that part of it which projects beyond the stroma of the ovary, and is only covered by peritoneum. This becomes more and more prominent, and finally bursts at the site of its greatest projection. Since the small opening thus made (*a*) lies exactly in front of the ovum (*f g h*), this rushes out, together with the zona pellucida (*e*) the germinal disc (*d*),—which is torn off at its circumference,—and the greater part of the follicular contents (*b*). The membrana granulosa (*c*) and the follicular membrane (*a*) remain in the ovary, to which they are firmly attached.

2155. The exsudation which causes the exit of the ovum is afterwards considerably increased. It gradually fills up the whole follicular cavity; and sometimes even projects in the form of a wart, as in the rabbit. It then forms a dense globular mass, which has been named the *corpus luteum*, on account of its yellow colour in man and some mammalia. It may however be greyish white, red, violet, or brown. It subsequently diminishes in bulk, at the same time becoming denser; and is gradually converted into a small roundish or oval nodule, leaving behind it a cicatrix which may finally disappear.

2156. The periodic rut of the brute mammalia (§ 2130) gives rise to an energetic determination of blood towards the female sexual organs. It is only at this time that the ova project from the ovary. A bloody fluid or mucous secretion then frequently comes from the vagina. The desire for coition is almost limited to this period; and appears to depend immediately on these phenomena of rut.

2157. The puberty of the human female is announced by the appearance of a flow of blood from the sexual organs. This discharge is called the menstrual flux; because, under normal circumstances, it is repeated once every month. It continues from the access of puberty to an epoch which is generally called the turn of life. It is only during this period that a woman is capable of being impregnated. During the age of childhood which precedes the access of puberty she is incapable of maintaining the species. And after menstruation has ceased, her generative organs are incapable of further fruitful action.

2158. The date at which menstruation begins and ends is liable to great variety. In our climate the menses usually appear between the age of 14 to 16 years, and cease between 40 and 45. Still very con-

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siderable differences are met with. In the natives of tropical climates, menstruation frequently begins between 9 and 11, and ceases between 30 and 35. On the other hand, in the high northern latitudes these periods of time are often delayed beyond the date at which they occur in the more temperate regions. Still there are negresses whose menses appear as late as those of some Swedish women; *e.g.*, for instance, at the age of from 20 to 21.

2159. In exceptional instances the menses return every one or two, or every five or six, weeks. But the ordinary time is exactly four weeks or 28 days. Extensive series of observations give this as the average. Since it is also the most frequent of all the periods, it is obviously a natural average, and not an accidental one.

2160. It has often been supposed that there is some relation between the menstrual discharge and the changes of the moon, since a single rotation of this satellite around the earth likewise demands 28 days. But this view is not based upon proofs such as are demanded by natural science. The menses appear at various days in different women, and often return a few days earlier or later in the healthiest individuals:—facts which are utterly unlike the fixed phenomena presented by the revolutions of the moon.

2161. In healthy women, menstruation does not itself lead to any special disorder. But when collateral causes interfere, morbid phenomena are more liable to occur than in most other normal actions. The appearance of the menses is often preceded by pain in the loins, nausea, colic, prostration, and even by febrile symptoms. And their continuance is sometimes accompanied by paleness of the face, blue rings round the eyes, headache, dulness of intellect, vomiting, tympanites, and various derangements of the abdominal viscera.

2162. The access of menstruation is sometimes immediately preceded by the discharge of more mucus than usual from the vagina. But to all appearance, it often commences as a flow of blood even in healthy women. After lasting some days, it is succeeded by a watery fluid, which continually diminishes in redness. This gradually becomes more colourless and scanty, until it is converted into a mucous mixture, which at last disappears.

2163. These successive changes prevent any exact estimate of the duration of menstruation. The pure sanguineous flux, and the reddened watery discharge, generally last from 4 to 6 days. But in women who menstruate but sparingly, they often last only 2 to 3 days; while in persons more inclined to hæmorrhage, they remain 7 or 8.

2164. The menstrual blood always contains a large number of blood-corpuscles (Tab. II. Fig. 25, *b c*). Although it is more fluid than ordinary blood, still it is not devoid of all capacity for coagulation (§ 1001). Microscopic examination sometimes shows a few masses of coagulated

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fibrine, especially in menstrual blood which is still contained in the uterus (Tab. II. Fig. 25, *a*). While those larger quantities of blood which flow from the genitals during and after parturition (as well as in the earlier part of the puerperal state, and in abnormal uterine hæmorrhages) coagulate in the ordinary manner:—namely, in larger masses, such as are at once recognized by the naked eye. Exsudation-corpuscles (§ 1053, Tab. II. Fig. 25, *d e f*) are also present; and in larger numbers, the more completely the proper sanguineous character of the discharge has disappeared (§ 2162).

2165. Disease sometimes causes the internal surface of the uterus to become everted, and project from the orifice of the vagina. In cases of this kind, the menstrual blood has been distinctly seen flowing from the mucous membrane of the uterus. But the way in which it is poured out is at present unknown.

2166. When a menstruous woman dies of any disease not directly affecting her sexual organs, a vast number of the blood-vessels of the ovaries and uterus are found greatly distended. On opening the uterus one or more days after death, we see lumps of coagulated blood (the constituents of which are represented magnified in Tab. II. Fig. 25.) At first the blood-corpuscles (Tab. II. Fig. 25, *b c*) are in large numbers; while the exsudation-corpuscles (*d e f*) are much less numerous. The coagulated fibrine (*a*) forms amorphous masses, which traverse the whole in various directions, and are soaked in the fluid in which the remaining solid structures swim. The liquid menstrual blood discharged from the living female is very muddy; but on being allowed to stand in a glass, it subsequently deposits a loose precipitate, which is composed chiefly of blood-corpuscles.

2167. During menstruation, the internal surface of the uterine mucous membrane consists of a greyish-white gelatinous substance. Examined under the microscope, this presents a transparent basis (Tab. II. Fig. 26, *a*), together with granular globules heaped together in the form of a pavement. Besides this we observe red points or spots, containing blood-corpuscles, or even portions of coagulated fibrine. Highly distended blood-vessels are seen through many parts of the gelatinous mass. This alteration in the internal surface of the mucous membrane precedes the appearance of the menses themselves. At any rate, it has been distinctly seen in the uterus of a young woman executed a few days before the return of menstruation.

2168. Hence before the hæmorrhage can itself force its way through, the lining membrane of the uterus is distended and partially loosened by an increased quantity of blood. Blood subsequently exsudes from various points; and is found, mixed with coagula, in the uterine cavity of the dead subject. The most obvious supposition is, that many of the blood-vessels rupture, and thus extrude their contents. This would at once explain the presence of corpuscles in the menstrual blood. But

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many think it more probable that the porosity of the walls of the vessels undergoes such a change as to allow the blood-corpuscles a direct transit.

2169. When the hæmorrhage has lasted some time, it is accompanied by an exsudation, which gradually supplants it. This change is indicated by a gradual increase in the number of exsudation-corpuscles, and by the colourless and highly saline characters of the fluid. The exsudation itself subsequently diminishes. Part of its mucous characters are probably due to the horny substance which it dissolves in its course, and to its being mixed with the mucous secretions of the vagina. Some epithelial scales from the external genitals are always present as a foreign constituent.

2170. We shall hereafter see that the mucous membrane of the uterus sheds its innermost layers during the puerperal state. Pouchet states that something similar to this occurs at the close of menstruation. The partially dissolved fragments of this membrane which are shed during the second week form a mucous substance, the exit of which marks the conclusion of the menstrual changes.

2171. The periodic loss of blood which we have just been considering is one of the most important vital actions of the fertile female. Its non-appearance at puberty, or its subsequent absence, causes a series of disorders which are comprised under the name of *chlorosis* or green sickness. This state is marked by a pale yellowish-green colour of the skin, blue rings round the eyes, prostration, dulness of intellect, and finally, dropsical effusion. The blood of chlorotic women contains fewer corpuscles than in health. The curative effects of the preparations of iron often used to remedy the disease are due to their obviating this fault of the blood. The healthy female gives off less carbonic acid as long as she is subject to this periodic hæmorrhage (§ 823). But, according to Hannover and Scharling, in chlorotic persons who do not menstruate, the quantity of carbonic acid is increased, although the number of blood-corpuscles is considerably diminished.

2172. When the *os uteri* (at *c*, Fig. 386, p. 630) is morbidly closed, the menstrual blood gradually distends the womb. The abdomen slowly acquires a bulk almost equal to that which it offers in a woman far advanced in pregnancy. But since the resistance offered by the walls of the uterus sooner or later obstructs the entry of new menstrual blood, chlorotic symptoms finally appear, together with other disorders which are immediately due to the abnormal enlargement of the uterus. On puncturing the occluded os uteri, there gushes out a large quantity of black and partially coagulated blood; which is extremely fœtid from putrefaction. If the artificial orifice is kept open, the uterus gradually resumes its normal size and activity. The chlorosis then ceases spontaneously.

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2173. The menstrual flux is only an external index of various important changes which the internal organs of generation undergo at these periods of time (§ 2159). Where absent, it is sometimes replaced by other hæmorrhages :—for instance, from the nose, lungs, or stomach. Such "metastases" of menstruation sometimes follow the extirpation of the uterus. According to Roberts, in those Indian women who have been castrated by the removal of the ovaries, there is no trace of either menses or metastatic hæmorrhage. This fact has been confirmed by many European cases in which both ovaries have been removed by surgical operations. But according to other medical narratives, the menses have sometimes continued in spite of this extirpation. Of course the loss of a single ovary will not prevent menstruation.

2174. Recent researches have established that the ovaries are the site of the most important of those changes which accompany the rut of the mammal. Formerly it was supposed that the discharge of the ova from the Graafian follicles (§ 2154) could only be produced by the action of the semen. The corpora lutea (§ 2155) were therefore regarded as a certain sign of previous impregnation. But the observations of Duvernoy, Pouchet, Raciborski, and (especially) Bischoff teach us that this is not the case. The vigorous sexual activity which obtains during the period of rut suffices to ripen one or more follicles. And this again requires the discharge of ova: and the subsequently development of corpora lutea.

2175. The periodical recurrence of rut—together with that discharge of blood from the genitals which accompanies it in some mammalia—have led many physiologists to suppose that the menstruation of the human female corresponds to the rut of the mammal. According to this idea, the rutting season of the human female recurs every four weeks all the year round. Although this comparison has lately received very important confirmation, still there are many important differences. While the sexual appetite of the animal attains its greatest height in the rutting season, the menstruating woman generally rejects coition, and either has no period of increased sexual excitement, or at most only betrays it for a short time after the last traces of sanguineous menstruation have ceased.

2176. The notion that the menstruation of the human female forms a parallel with the rut of mammalia has led to the conjecture that one or more Graafian vesicles discharge their ova during this flow. Many observers have in fact found a ruptured follicle or a recent corpus luteum in one ovary of women who have died shortly after the end of menstruation. But under similar circumstances, others have been unable to discover any evacuated follicles. Still it may be questioned whether, in these cases, death did not occur at so early a period, that the sexual excitement only sufficed to produce the menstrual flux, without attain-

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ing that intensity requisite for the expulsion of ova. Others believe that corpora lutea may arise independently of menstruation in children and old women: or that there are two varieties of these bodies; — the true, which result from menstruation, and the false, which are due to other causes. There is no doubt that diseased states of nutrition are capable of converting the follicles into watery vesicles, or of producing exsudations similar to corpora lutea and cicatrices. But at present we have no proof that true corpora lutea can be normally developed except during the age of menstruation, or that they are ever found in the ovaries before or after this period.

2177. The oviducts or Fallopian tubes of the human female (*f*, Fig. 386, p. 630) and most mammalia have no immediate connection with the ovaries (*e*). Their cavity rather opens into that of the abdomen. A row of fringes or fimbriæ (*g*) occupy their dilated apertures, the incised margins of which are called the *morsus diaboli*.

2178. On the ovum preparing to emerge from the follicle, the fimbriæ (*g*, Fig. 386) of the Fallopian tube (*f*) grasp the ovary. The cause of this peculiar phenomenon remains at present unknown. Since unstriped muscular fibres are contained not merely in the Fallopian tube itself, but also in the mesentery by which it is suspended (above *e* on the left), this process is perhaps due to a contraction of these structures. The ovum (§ 2154) expelled from the follicle then falls into the cavity surrounded by the fimbriæ (*g*). It thence passes onwards in the Fallopian tube (*f*), and finally gains the uterus (*a b*), into which this canal (*f*) opens (*x*).

2179. If a doe rabbit be shut up alone during rut, and thus prevented from copulating, several of the minute ova which have been expelled may be subsequently found occupying its oviducts or the cornua of its uterus (§ 2154). Since the ciliary movement of the internal female organs propels the substances in contact with them in a direction from within outwards, it is perhaps capable of assisting the progress of the ovum. The peristaltic contraction (§ 1297) of the oviducts themselves could propel the delicate germ still more quickly.

2180. We have already (§ 2154) seen that not only the ovum, but the zona pellucida and the germinal disc (which is torn off by its margin), are expelled from the follicle. And, according to Bischoff, even should the whole mass meet with no semen on its way, it still undergoes a change. This change is represented, as seen in the rabbit, by Fig. 388. The cell-like bodies of the germinal disc, which lie on the zona pellucida and the less transparent ovum, are prolonged into a fusiform shape. The vitelline substance afterwards collapses irregularly, and finally disappears, probably by a gradual absorption.

2181. *Impregnation* consists in the material contact of the two kinds of germinal substance formed by the secretions of the testicle and ovary;

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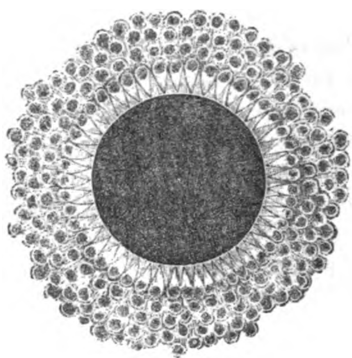
or of the mature semen, and the ova that have attained a certain stage of development. The external impregnation of frogs and fishes (§ 2086) would alone justify us in concluding that the mutual action of these structures is sufficient for embryonal development. It also explains what is called artificial impregnation.

2182. On compressing the belly of a female fish in the spawning season, numerous ova are discharged from its genital aperture. If these be permitted to fall into water, and a similar experiment repeated with a rutting male of the same species, artificial impregnation may be effected. Under favourable circumstances, the ova are developed, and the young emerge. The same procedure is often successful with the semen and ova of frogs, as well as with those of many invertebrate animals. Hunter even relates an instance in which a woman became pregnant after the artificial injection of semen into the vagina. And in dogs this process has often been attended with success.

Fig. 388.



2183. In such experiments it is by no means necessary that the semen and ova should be those of living animals. But the immediate contact of the two is essential. The semen exercises no action at a distance. What has been called the *aura seminalis*, i.e. a vapour which was supposed by earlier authors to arise from the semen, and to reach and fertilize distant ova—does not really exist. On the other hand, the direct contact of an extremely small quantity of semen, which has been mixed with a suitable fluid, will suffice to excite a large number of eggs to the development of their embryos. These effects therefore depend on quantities the minuteness of which will bear a comparison with those seen in any other contactive action (§ 299).

2184. The movement of the spermatozoa seems (§ 2126) to constitute an essential condition of impregnation. Most observers agree that semen which contains either no seminal filaments or such as have lost their activity, is incapable of exciting the ova to embryonal development. Hence the sterility of some men has been explained as due to their testicles being unable to secrete a semen provided with moving corpuscles. And recent observers—such as Prevost, Dumas, and Schwann—agree in the statement, that frog's semen which has been diluted and deprived of its spermatozoa by filtration is insufficient for impregnation. But Spallanzani asserted that he had effected impregnation with such *liquor seminis*.

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2185. The action of the semen at once renders the ovum capable of undergoing a gradual change in its several parts—a change which, under favourable collateral circumstances, sooner or later gives rise to a new and independent being. The resemblance which this often bears to its father shows how materially the seminal secretion assists in determining those changes which the ovum undergoes. This statement is confirmed by the generation of hybrids; where the two germinal substances belong to different (though allied) species of animals.

2186. At present we are ignorant of the nature of this important influence exerted by the semen on the destinies of the ovum. Many physiologists refer it immediately to the spermatozoa; because these structures exhibit peculiar forms in different animals, and in the seminal secretions of some polyps and entozoa, appear to be unaccompanied by any liquor seminis. As regards the latter argument, it is certain that a minute quantity of fluid is contained in all animal structures, and hence in the semen. As regards the former, a species presenting spermatozoa of the same form, is often quite incapable of effecting artificial impregnation, or producing a hybrid. And even apart from this, it must be admitted that we have as yet no clear hypothesis of the immediate action of the seminal corpuscles. These evidently exert an influence which we cannot in any way define.

2187. A second view, which at least affords a more distinct idea, supposes that the liquor seminis penetrates the ovum by endosmose (§ 129). The contactive action (§ 299) of minute quantities of its constituents gives the impulse to the further evolution of the ovum. Hence the effects of the exciting body (*i. e.* of the fertilizing semen) are manifested in the form of the new being (§ 8).

2188. In such a theory, the movements of the spermatozoa may be regarded under two points of view. One of these supposes that they are only an outward expression of the progressive molecular changes due to their capacity for contactive action (§ 2183). The second hypothesis is based on a comparison of their character with those of certain unorganized compounds. There are some solutions which only remain unchanged so long as they continue in perpetual movement. The restless activity of the spermatozoa might similarly help to maintain the seminal fluid in its proper state of admixture.

2189. The act of coition is merely an expedient selected by nature in order to bring the two generative substances into contact. But the collateral circumstances connected with it at the same time subserve the purpose of securing the due performance of the generative act. For as this function is not indispensably necessary to animals, it would therefore be, in itself, more indifferent to them. Hence the voluptuous feelings that generally accompany coition form, as it were, a bait which nature throws out in order to attain her main object—namely, the main-

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tenance of the species. And these sensitive impressions also lead to many reflex phenomena, which greatly favour the passage of the semen to the ovum.

2190. Erection of the penis is not a necessary condition of seminal emission (§ 2140). The ovum may therefore be impregnated without it (§ 2182). The act of coition may also be effected with a semi-relaxed penis. But erection greatly facilitates this act; and furnishes collateral conditions which are capable of assisting impregnation itself.

2191. The increased bulk and hardness of the penis cause it more completely to fill the vagina; and thus enable those portions of skin from which the voluptuous sensations proceed to glide more energetically to and fro on the soft mucous surface of the female genitals. According to Kobelt, these sensations produce reflex (§ 1937) alternating spasms of the acceleratores urinæ: which muscles press on the erectile tissues of the bulb of the urethra (*a′*, Fig. 382, p. 626), propel its blood further forward, and thus cause an additional increase in the bulk of the penis, and especially of its glans.

2192. The female organs of generation also undergo various changes under the influence of voluptuous excitement. The clitoris, the labia interna, and the neighbouring portions of the walls of the vagina, all contain erectile tissues; the structure of which corresponds with that of the corpus cavernosum of the penis. Hence lascivious mental impressions are capable of stiffening these parts. In addition to this, the vaginal walls contain unstriped muscular fibres, and possess a special muscle (the constrictor cunni) which is provided with striped fibres. The vagina itself is therefore capable of continuous contraction, or alternate changes of diameter. The increased secretion of mucus mitigates friction, and hence adds to the delicacy of the voluptuous sensations in both sexes. But the first attempts at coition are generally painful, since the penis ruptures the hymen (below *z*, Fig. 9, p. 34). The furrows which occupy the vagina of the married woman can remarkably increase friction.

2193. The mechanical stimulation of the vagina probably excites reflex movements in the internal and middle segments of the female generative apparatus. Thus we may conjecture that the uterus becomes more upright at this time, and descends somewhat deeper in the pelvis. The os uteri acquires a more circular form, and probably opens from time to time. All these changes would favour the transfer of the emitted semen to the uterine cavity. And the simultaneous contraction of the Fallopian tube (*f*, Fig. 386, p. 630) in a direction from the ovary (*e*) towards the uterus (*a b*) would be capable of propelling the previously expelled ovum more rapidly than the ciliary current of its mucous membrane (§ 2179). Hence the semen and ovum would be brought more speedily into contact.

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2194. On opening the body of a female mammal one or more days after it has received the male, semen may be found not only in the body and horns of the uterus, but also in the oviducts, and on the surface of the ovary. The spermatozoa are in vigorous movement. These may retain their activity for a week or more in the female organs. And in many insects this period of time is much greater. Here the ova are only expelled long after copulation. The females therefore possess a special receptacle (or *bursa copulatrix*), in which the moving spermatozoa are preserved until the ova finally reach them. In this receptacle their activity remains uninjured for many months.

2195. Since the ciliary movement of the internal female organs propels the substances in contact with them in a course from within outwards (§ 1203), it could only forward the semen by suddenly reversing this direction. But the vermicular movements of the uterus and oviduct would be capable of furnishing a rapid and powerful propulsive force. Still, as the spermatozoa of rabbits appear to require at least six hours to pass into the oviduct, and afterwards only traverse this canal slowly, we are justified in concluding that at any rate the semen is not propelled rapidly by vigorous movements of the uterus and Fallopian tubes. Hence many physiologists have supposed that the spermatozoa penetrate the recesses of the organs of generation by means of their own motive force.

2196. From what has already been stated we are justified in conjecturing, that the site of the act of fertilization or impregnation — *i.e.* of the mutual contact of the semen and ovum—depends upon accidental and collateral circumstances. If the ova previously expelled (§ 2176) have passed onwards into the oviduct (*f*, Fig. 386) or the uterine cavity, they will meet the semen sooner than if they had not left the follicle at the time of copulation. But the fact that the semen of the dog sometimes reaches the surface of the ovary (§ 2194) entitles us to suppose that the ova may be impregnated immediately on their exit from the follicle.

2197. Those ova which leave the ovary, and do not come into contact with any semen, after a time gradually perish (§ 1280). Many observers have believed that this fact essentially determines the epoch during which a woman is capable of being impregnated. They suppose that the ovum is only expelled at the time of menstruation. Hence impregnation may occur in the week immediately following, but not later. So that coition can only attain its true purpose from 8 to 12 days after the end of menstruation.

2198. The general experience of accoucheurs certainly shows that the possibility of pregnancy is much increased at this period of time. But we have no right to assert that coition during the last 14 days of the menstrual interval is necessarily fruitless. For various collateral circumstances

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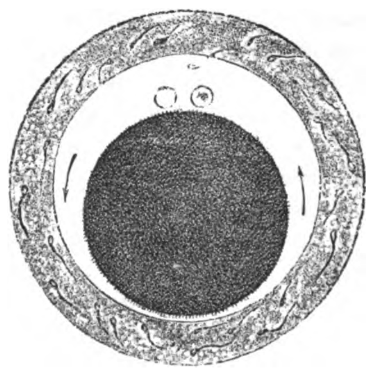
might greatly affect the result. In the first place it is not impossible that the later expulsion of an ovum would allow it to retain its capacity of development longer than 12 days after the cessation of the menses. It is even possible that the act of coition, or the contact of the semen, can excite the expulsion of an additional ovum from some mature follicle. While the semen which has reached the Fallopian tubes may perhaps retain its vigour even on the appearance of a second menstruation some days after coition. The short intervals of the rut of the human female would thus give rise to a series of apparent anomalies.

2199. The mammalian ovum which has already lost its germinal disc (§ 2151) and reached a certain degree of development, has been frequently observed to be surrounded by numerous spermatozoa. In Fig. 389 this is represented (after Bischoff) from the rabbit. Here the ovum had gone so far as to exhibit that rotation of the yolk which will subsequently be mentioned. The statement,—that a seminal filament penetrates through a fissure of the zona pellucida (*e*, Fig. 387), or that it forms the immediate foundation of the new being or of its nervous system—is not confirmed by recent researches. After some time, no traces of semen can be detected in or upon the more developed ovum.

FIG. 389.



2200. *Pregnancy.* Since the mammalian embryo is developed in the uterus, this organ has to undergo a gradual enlargement, which corresponds to the growth of the new being and the structures it requires. In this process the uterus is not merely extended, but undergoes a series of profound and important changes, which we shall consider partly here, partly in describing the membranes of the ovum.

2201. Under morbid circumstances it may happen that the human ovum does not reach the uterus, but undergoes a more or less complete development in some other place. There are four distinct forms of this extra-uterine pregnancy; ovarian, tubal, abdominal, and interstitial. In ovarian pregnancy the ovum is supposed to be developed to a certain stage in the substance of the ovary. Abdominal pregnancy has been attributed to the fact, that the fimbriæ of the Fallopian tubes (*g*, Fig. 386, p. 630) fail to grasp the ovary (*e*) at the instant the ovum is expelled (§ 2178). Hence this falls into the abdominal cavity, and sinks to its deepest part between the uterus and rectum (*w* and *y*, Fig. 9, p. 34), to undergo its further development. In tubal pregnancy the

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ovum remains in the Fallopian tube without reaching the uterus. Finally, in interstitial pregnancy the embryo and its accompanying structures occupy an interstice of the uterine wall.

2202. A closer analysis of their circumstances renders it very probable that all these varieties, however different from each other, proceed from a tubal pregnancy. Thus it sometimes happens that the ovum fails to reach the uterus. It then grows for two or three months in the Fallopian tube. This finally becomes so extremely distended by the increased bulk of the ovum, as to be ruptured in some part. A fatal hæmorrhage frequently accompanies this injury. In such a case, an examination of the body shows it to be a proper tubal pregnancy. But sometimes the development of the embryo is not checked so early, and the mother survives the final rupture of the tissues which enclose it. In rare instances of this kind, the sac enclosing a more advanced fœtus is found lying in the abdominal cavity, above the uterus, and between it and the umbilical or epigastric region (υ, η, θ, s, Fig. 9, p. 34); being connected by numerous exsudations with the neighbouring intestines. But after such a rupture, the embryo generally sinks by its own weight into the space between the uterus and rectum (w and y, Fig. 9). Here it may remain for years, finally becoming shrunken and calcified. Sometimes, after many years, it gives rise to inflammation and suppuration, producing abscesses and fistulous openings into the rectum or its neighbourhood. Some of the fœtal bones may then emerge from these sinuses, either spontaneously or aided by the surgeon's forceps. Such phenomena constitute what is called abdominal pregnancy.

2203. There is probably no such thing as a true ovarian pregnancy, in which the fœtus attains any bulk. What have been regarded as such were most likely nothing but tubal pregnancies, in which the ovisac occupied the neighbourhood of the abdominal opening of the Fallopian tube (between f and g, Fig. 386), and only united with the ovary by means of subsequent exsudations. Finally, interstitial pregnancy is produced by the ovum remaining attached at the point where the Fallopian tube opens into the uterus (x, Fig. 386, p. 630), so as to form a globular enlargement here.

2204. It has often been maintained that a woman who is already many months advanced in pregnancy may be again impregnated, so as to bear a mature child twice in the course of a few months. But we shall hereafter see that, even in the earlier months of pregnancy, the ovum completely fills the whole uterine cavity. Hence a new impregnation—or a superfœtation, as it is called—could only occur under very abnormal circumstances. The further development of a second ovum would be opposed by still greater difficulties. We are therefore entitled to suppose that, with the normal single uterus, superfœtation after an interval of many months is impossible. But many have believed that,

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in women who have brought forth a mature child some months after their first delivery, the uterus has been double — possessing two cavities or cells. Even this conjecture, however, is met by a new difficulty. During pregnancy, menstruation is generally absent. Yet without the spontaneous expulsion of an ovum (§ 2176) the second impregnation cannot be explained. But since the literature of these supposed cases of superfœtation defies all satisfactory criticism, it remains for the future to decide the reality of the occurrence. In any case, it is important to remember that the birth of one twin is sometimes delayed to a period considerably later than that of the other.

2205. In some women, the commencement of pregnancy is betrayed by nausea and vomiting. This disorder, which is often completely absent, or is limited to the first pregnancy, sometimes remains for months in spite of all medicines. It usually ceases spontaneously in the latter half of pregnancy.

2206. The menses are generally absent during the whole period of pregnancy. Hence women often calculate the time of conception and delivery from the date at which the menstrual discharge first fails to appear. But differences are sometimes met with in this respect. Menstruation may return once or oftener after the effective act of coition; or may habitually remain during the whole pregnancy. Instances are even known in which women have only menstruated during this state.

2207. The uterus, the bulk of which is continually increased by the enlargement of the ovum, sinks somewhat deeper into the pelvis at the beginning of pregnancy. Subsequently it rises again, but in the earlier months remains confined to the region of the pelvic cavity (*v*, Fig. 9, p. 34). Its fundus reaches the navel (*9*) in the sixth lunar month of pregnancy, and the epigastric fossa (*t*) in the ninth. In the tenth, it again descends slightly, so as to reach the region indicated in Fig. 390. Here *a* is the vagina; *b* the uterus, in which the fœtus is indistinctly seen through the membranes, while its fundus is occupied by the placenta. At *c* is the symphysis pubis; *d* is the urinary bladder, *e* the navel, *f* the rectum, and *g* the promontory which forms the junction of the lumbar and sacral vertebræ. It will be seen that the enlarged uterus pushes before it the abdominal walls, compressing the opposed viscera of the belly, and constricting the bladder, the rectum, and the great vessels of this cavity. To these circumstances we may refer a variety of disorders met with in pregnant women: — such as involuntary evacuation of urine in coughing or sneezing, difficult evacuation or constipation of the bowels, varicose veins of the thighs and lower extremities, pains in the legs, &c.

2208. According to Levret, the uterus in advanced pregnancy occupies 500 times the space of the unimpregnated organ. And although its proportionate increase of weight is less considerable, still its mechanical

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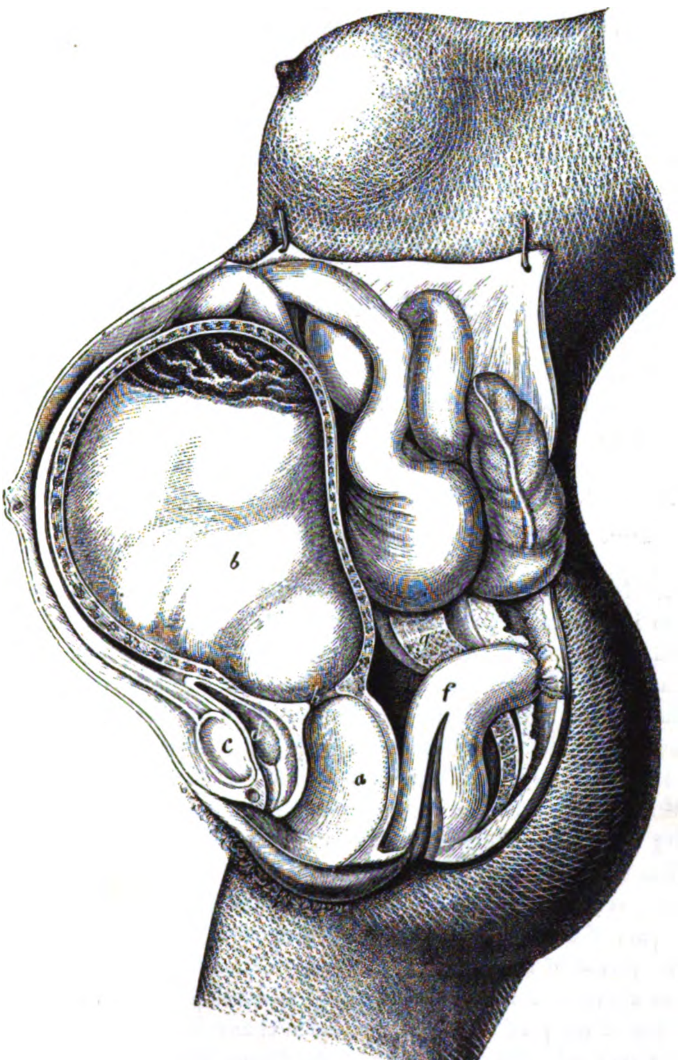
extension is accompanied by at least some increase of substance. Its blood-vessels are increased in both size and number. And its unstriped muscular fibres, some of which are very large, are seen much more

FIG. 390.



easily than in the unimpregnated organ. The general course of its nerves does not appear to be materially altered. But some observers believe that they have verified an increase of the grey nervous elements.

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2209. While the anterior lip of the os uteri (*c*, Fig. 386, p. 630) of the virgin generally projects lower than the posterior, even in the earlier months of pregnancy the two lips are frequently at nearly equal heights. They afterwards swell considerably, and become more arched, so as to give the os uteri a rounder form. Towards the close of pregnancy the neck or vaginal portion of the uterus (above *z*, Fig. 9, p. 34) continually shortens, in consequence of a larger part of the organ being claimed by the embryo and its membranes. The internal and external os uteri thus come to occupy nearly the same transverse plane (*h*, Fig. 390, p. 645). All these phenomena are best seen in the first pregnancy.

2210. *Development of the Embryo.* The mature ovum consists of a definite aggregation of fluid and solid tissues; which easily alter under the influence of external circumstances. Thus the mere change of residence which the ovum undergoes on its spontaneous expulsion gives rise to certain phenomena of development, even where it has not been impregnated (§ 2180). But the fertilizing semen has a twofold action of the same kind. It increases the changeability of the constituents of the ovum; and evokes in them a chain of phenomena, each link of which conditionates those that follow, and ends in the production of the new animal (§ 8). It also determines the direction of development; and by doing so, impresses upon the new creature the visible stamp of its own individuality. The resemblance frequently seen between the father and offspring depends upon this collateral influence of the semen (§ 1285).

2211. Heat, which dilates and relaxes all kinds of matter, and which plays so important a part in most chemical changes, often forms an essential condition of embryonal development. The specific heat of the mammalia (§ 1158) at once furnishes the requisite temperature. But the ova of birds require the assistance of the act of incubation. The vessels of that part of the hen's belly which covers the ova during incubation undergo a considerable development at this period. They thus form what is called an organ of incubation, containing an increased quantity of blood,—which not only furnishes more heat (§ 1177), but is capable of maintaining this higher temperature in an uniform state, in spite of external losses. An elevation of temperature may also be noticed in that part of the body which protects the ova of the larger snakes during their period of incubation. The favourable influence of heat is even manifest where it is much less necessary to development. If a number of the ova of the pike be placed in a warm chamber, and a second quantity in a very cold one, the young of the former are sometimes hatched twice as soon as those of the latter.

2212. As regards the phenomena of incubation, it makes no difference whether the necessary heat is furnished by an animal, or by any other source. Hence the impregnated eggs of birds may be artificially hatched

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in an incubating apparatus;—*i.e.* in an apparatus which maintains them at an uniform temperature between 95° and 100°.

2213. In order that the embryo should be gradually developed from the elements of the ovum, these must enter into mutual action with certain external matters. It is only this mutual and material action which causes the evolution of the requisite series of germinal substances and cells, and of the subsequent groups of permanent tissues. Thus from the first moment of embryonal development, there is a manifest need of nutriment. In the egg of the bird, these objects are partially fulfilled by the external calcareous shell, the albumen, and the yolk. The surrounding atmosphere only furnishes the oxygen which is further requisite for the development of the new being. Many ova which are developed in water may withdraw other substances from it. But although a yolk and an albumen are also at the disposal of those creatures which come into the world alive, still the greater part of their nutriment is derived from the juices of their mother, whom they inhabit during incubation.

2214. Many ova and embryos are soon destroyed by a deficiency of their proper nutriment. But in some instances, this disadvantage does not cause the destruction of the new being, but only keeps back its development, or gives rise to partial abnormal changes. For example, an extremely spare diet sometimes causes the tadpole to remain many months in this stage of development. And one fœtus of twins is often very much emaciated.

2215. The germinal vesicle (*c*, Figs. 369, 370, p. 609, and *g*, Fig. 387, p. 631), which forms an essential characteristic of the unimpregnated ovum, disappears as soon as the development of the embryo commences. The ultimate destiny of this remarkable structure has been the subject of various hypotheses. Thus it has been supposed that the vesicle becomes flattened and converted into a thin membrane, or that it surrounds the germinal spot (*d*, Fig. 369, *h*, Fig. 387, p. 631) with secondary cells, out of which the embryo is constructed. But recent researches have not confirmed either of these opinions. The same statement applies to another theory, according to which the germinal vesicle bursts, and the germinal spots are distributed through the remainder of the yolk (*a*, Fig. 369, and *f*, Fig. 387), to form the nuclei of those cells of fission which we shall hereafter mention. Many have supposed that the germinal vesicle of the snail passes out into the vitelline mass, and is there destroyed;— the relics of the germinal spots being retained in the form of those small vesicles which are subsequently met with in the albuminous substance around the yolk. In the mammal, similar roundish corpuscles are also interposed between the vitelline substance and the zona pellucida. Such, for instance, may be recognized in the representation of the rabbit's ovum given in Fig. 389, p. 642.

2216. Most of the facts hitherto known appear to indicate that the

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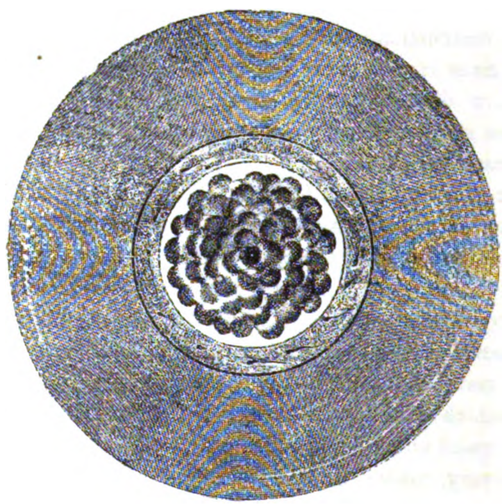
germinal vesicle bursts, and that its contents are more or less completely poured out into the remaining mass enclosed by the vitelline membrane (*b*, Figs. 369, 370). This foreign admixture has the immediate effect of exciting the germinal structures of the yolk to a series of new changes; — to an alteration of form, and of atomic grouping. The fission or cleaving of the yolk is the first and most prominent effect of the impulse thus given by the contents of the germinal vesicle. The destiny of the germinal spots is at present undecided.

2217. The ovarian ovum (*f*, Fig. 387, p. 631) contains a spherical yolk. In the rabbit and dog the fission or cleaving of the yolk begins by the constriction and separation of this sphere into two portions, which are also spherical. Each of these is again subdivided into two segments, making four in all. The fission subsequently proceeds in a similar way; until finally, the entire yolk resembles a mulberry. This stage of development in the rabbit's ovum is represented by Fig. 391, after a drawing by Bischoff. Since the size of the several spheres continually diminishes as

FIG. 391.



their number increases, the surface of the yolk at last almost recovers its former smoothness; so that the progressive partition of the ovum finally results in minute cells which can only be seen under the microscope.

2218. Since this process implicates the whole surface of the yolk, it is called the general or total fission. It occurs not only in mammalia, but also in frogs, and in many invertebrate animals (*a*, Fig. 374, p. 614). In many other animals—such as birds, the osseous fishes, and some invertebrata—the ovum undergoes a partial vitelline fission. The cleaving proceeds like that already described; but it only includes that particular

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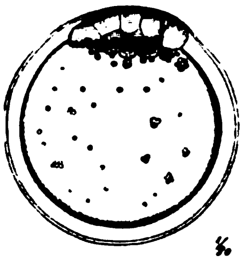
segment of the ovum out of which the first rudiments of the embryo are subsequently formed. This process is represented by Fig. 392, as it occurs in the ovum of the pike.

FIG. 392.



2219. Like the germinal vesicle of the unimpregnated ovum, the fission of the yolk obtains in all classes of animals except the true *Infusoria*. It now and then occurs to a certain extent in the unimpregnated ovum also—for instance, in that of the frog. It consists essentially in an aggregation of the elements of the yolk or germinal substance to form globular heaps. These then produce nuclei in their interior. A membrane which is subsequently added encloses and limits the entire mass; and thus gives rise to what is called a cell of fission. The contents of one such cell are again divided into spherical heaps, which are converted into smaller cells of fission; while the limitary membrane of the enclosing parent cell is subjected to the same process of solution as that which previously removed the membrane of the germinal vesicle. Finally, the last and smallest cells of fission form the minute elements of the rudimentary embryo.

2220. We have already (§ 1202) seen that the young of some animals exhibit a ciliary movement (§ 1195) on their outer surface, after emerging from the ovum. The same movement also occurs in the embryos of snails and muscles which still occupy the ovum. The comparative lightness of their body then causes them to undergo a continuous rotation (§ 1202). The larvæ of frogs rotate within their ova from the same cause. Finally, Bischoff has observed a similar rotation of the yolk in the rabbit. The ovum on which this observation was made is represented (magnified) by Fig. 389, p. 642. Its exterior was clothed with cilia, and it rotated upon its axis in the direction indicated by the arrow.

2221. After the partial vitelline fission (§ 2218) of the ovum, the corresponding segment of the yolk becomes covered by a membranous substance, the germinal membrane or blastoderm. And where the fission is general, the yolk is subsequently surrounded on all sides by a vesicular germinal membrane. But the name "germinal membrane" is frequently applied to both.

2222. The first rudiment of the embryo appears in a definite part of the germinal membrane—viz. its centre. The remaining portion or periphery of this membrane furnishes a series of ovuline structures, which are destined to the protection and nutrition of the new being. Others are contributed by the ovary; and in mammalia, the uterus furnishes additional structures of the same kind.

2223. The germinal membrane gradually splits up into several

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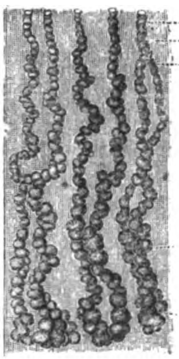
super-incumbent layers. Adopting the expressions proposed by Doellinger, Pander, and Baer, the uppermost portion of the membrane, which adjoins the vitelline membrane (*a*, Fig. 369, p. 609), is called the *serous*, and the middle the *vascular lamina* or layer. The undermost, which lies nearest the yolk, is called the *mucous lamina*. But Reichert and Remak state that the fission takes place in a different manner.

2224. The mucous membrane of the human uterus swells considerably after impregnation. Its free internal surface forms a semi-transparent greyish-white substance, which apparently possesses some villi. But a closer examination shows that this appearance is altogether deceptive, being caused by an increased development of its tubular glands. Long and somewhat lobulated tubes (*b*, Fig. 393), which sometimes divide (*d*), and which open on the free surface (*c*) of the uterus, lie imbedded in the substance (*a*) of its mucous membrane. They are sometimes seen very plainly in the uterus preparing for menstruation (§ 2167). On the other hand, they are often not to be found: especially in the uterus of aged subjects.

FIG. 393.



2225. The innermost portion of the relaxed mucous membrane of the uterus forms what is called the *membrana decidua*. But the change just described precedes the passage of the ovum into the uterus (§ 2177). This explains why what is called a deciduous membrane occurs in tubal pregnancies (§ 2201), if not interfered with by menstruation or other collateral circumstances.

2226. As the ovum enters the uterus, it is received by one of the numerous folds of the internal surface of its mucous membrane. A part of this forms a capsule for it. Hence the membrane offers two portions: one of which occupies the walls of the uterus, and is named the true decidua. While another part of it, which surrounds the ovum and grows with its growth, is called the false, reflected, or secondary decidua. Another membrane improperly called a decidua is formed by that part of the true one which afterwards intervenes between the maternal and fœtal placenta (§ 2234).

2227. We shall hereafter see that a great part of the relaxed mucous membrane of the uterus is cast off with the placenta, and during the puerperal state. But in abortion during the earlier months of pregnancy, a part of the deciduous membrane is often destroyed with the ovum. Such an ovum in the second month, which was examined by R. Wagner, is represented in Fig. 394. Here *a* is a fragment of the *decidua vera*, and *b* a similar piece of the *decidua reflexa*.

The *chorion* is that villous membrane of the ovum which is indicated

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by *e* in Fig. 394. At *c* is the *albumen*, which lies between the *chorion* *e*, and the *amnion d*. The latter membrane contains a fluid, the *liquor amnii*, in which the embryo *g* floats. What was formerly the yolk

FIG. 394.

occupies a special vesicle, the umbilical vesicle *f*; a long and slender prolongation of which, the vitelline or umbilical duct, leads to the intestine of the embryo *g*.

2228. The chorion and albumen of the hen's egg are formed during its transit through the oviduct. Hence many have supposed that, in the mammal, these parts are deposited in the Fallopian tube (*f*, Fig. 386, p. 630). Others think that a special mode of development must be assumed for the latter class of animals. They suppose that the zona pellucida (*e*, Fig. 387), swells out considerably in the tube (Fig. 389, p. 642, and Fig. 391, p. 648). It thus gradually produces an albuminous mass; the external layer of which either hardens to form the chorion, or becomes surrounded by it in the shape of a new membrane.

2229. The chorion is at first smooth. A few villi then project from its surface. Their enlargement and multiplication finally give rise to the villous or shaggy appearance represented at *e*, Fig. 394. We shall hereafter find that a large portion of these prolongations serve to form the fœtal placenta. After this has been constructed, the remaining surface of the human chorion appears almost smooth :—only a few small and scattered villi being retained up to the period of birth.

2230. The accompanying diagram (Fig. 395) may assist to explain the origin of the amnion. It represents an imaginary vertical and

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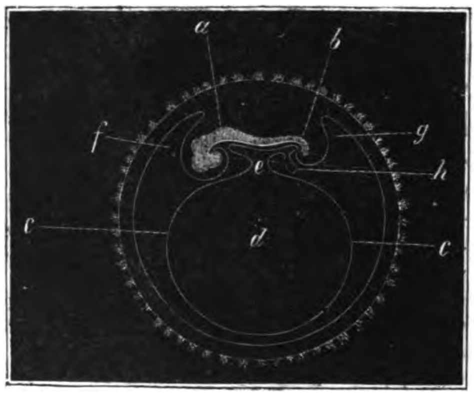
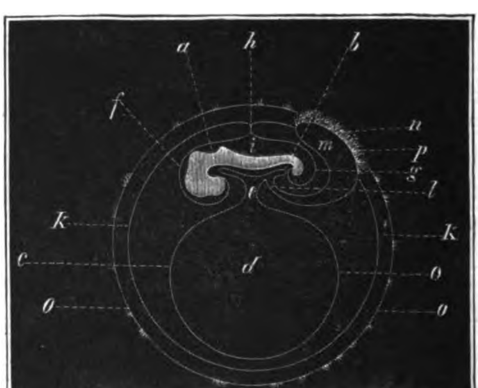
longitudinal section; where *a b* is the centre of the serous lamina (§ 2223) of the germinal membrane (§ 2221), which has already been metamorphosed into some of the embryonal organs. The adjoining portions of its periphery are prolonged as two double folds—the ***involucrum capitis*** *f*, and *caudæ g*—over the embryo *a b*. Similar processes

FIG. 395.



are also formed to the right and left. Those folds are gradually raised and separated from the embryo by the interposition of a fluid, the first rudiment of the future liquor amnii; and they then approach each other, until finally they meet. The vertical section which corresponds to this stage of development is represented by Fig. 396, in which *h* forms the

FIG. 396.



point of union or suture of the different involucra. By this process two membranous structures are produced. The external one *k k* is a serous tunic, which, like the vitelline membrane (*a*, Fig. 369, p. 609), disappears in course of time. The inner one *f g* is retained as the amnion.

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2231. The quantity of the liquor amnii (*i*, Fig. 396) is increased as development advances: while its percentage of albumen and solid residuum gradually diminishes. The amnion acquires a similar increase of bulk. In the meantime, the albumen (*c*, Fig. 394, p. 651) which lies between the chorion (*e*) and the amnion (*d*) is extended, so as to form a membrane of continually decreasing thickness, until it is finally reduced to an inconsiderable deposit between these two membranes of the ovum.

2232. The germinal membrane (§ 2221) at first encloses the remainder of the yolk on every side (*d*, Fig. 396). The central portion of its mucous layer subsequently becomes the intestinal canal, while the peripheric forms a vitelline membrane (*c c*), which replaces the previous one (§ 2083). This then constitutes the membrane of the umbilical vesicle (*f*, Fig. 394, p. 651), the further development of which gradually causes it to recede from the intestine, so that an intervening portion, the umbilical duct (*e*, Fig. 396), is drawn out between the two. In the human subject the umbilical vesicle (*d*, Fig. 396) then speedily atrophies. It finally either disappears, or remains up to the time of birth as a collapsed yellowish sac that occupies the cavity of the albumen between the chorion and amnion (§ 2227).

2233. In the young embryo of the bird and mammal we observe a special vesicle—the urinary sac or *allantois* (*h*, Fig. 395)—which emerges from the opening left by the unclosed abdominal walls, and penetrates the space occupied by the albumen. Its cavity communicates with that of the end of the intestine. It subsequently enlarges, and is either opposed to the chorion by its outer surface (*m*, Fig. 396), or at any rate occupies its immediate neighbourhood.

2234. The umbilical arteries, which at first form the terminal prolongations of the aorta, produce a vascular network, the *endochorion*, which is distributed upon the allantois. It subsequently sends off shoots into the opposed villi of the mammalian chorion (*o p*, Fig. 396). The highly vascular portions of these prolongations of the chorion form the fœtal placenta, or that part of the ovum which is the especial agent of its reaction on the maternal blood. The uterus presents corresponding irregularities, which are traversed internally by numerous vessels of the mother, so as to form the maternal placenta. The union of these two vascular organs constitutes the *placenta* in the wider sense of the word. They are mutually connected with each other; more loosely in some mammals, more closely in others. But the maternal vessels of the placenta are never immediately continuous with those of the fœtal placenta or the embryo itself. Hence the blood of the mother and the fœtus can only act on each other by endosmosis (§ 129).

2235. A special cylindrical connection, the naval string or umbilical cord (*c*, Fig. 397), passes between the (now closed) abdomen of

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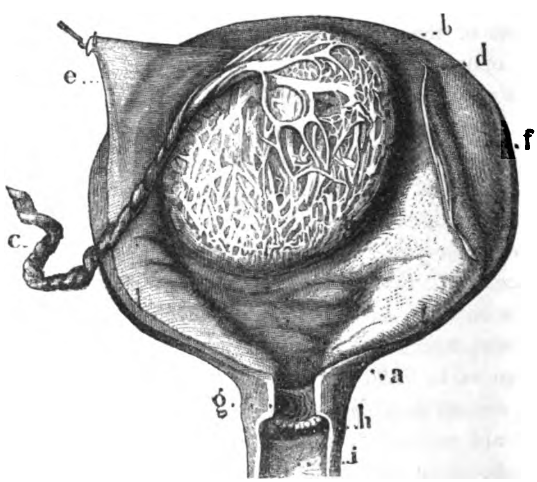
the embryo and the placenta which lies at some distance from it. It consists of a gelatinous substance, a few nerves (which can only be seen with difficulty), the two umbilical arteries which conduct the blood of the embryo to the fœtal placenta, and the umbilical vein which returns it from hence. All these blood-vessels take a spiral course to the placenta.

2236. The human ovum is distinguished by many peculiarities in this respect. At a very early period, its allantois can no longer be recognized. The fœtal placenta, which forms a single projecting mass, and which is only divided into cotyledons where it is opposed to the maternal placenta, is so closely united with the latter, that the two cannot be separated from each other without rupturing the vessels of both. Hence that separation of the embryonal placenta which follows the birth of the child is accompanied by hæmorrhage. Finally, that part of the human uterus which produces the maternal placenta is distinguished by the diameter of the vessels that unite its arteries and veins. These are so large that some of them can be recognized by the naked eye. The veins themselves form numerous plexiform networks, which resemble sinuses, and have walls that appear to be characterized by great delicacy where they adjoin the maternal placenta.

2237. The annexed woodcut (Fig. 397) represents the fresh uterus of a woman who died suddenly in the last month of pregnancy. Here *c*

Fig. 397.



indicates the umbilical cord, and *b* the fœtal placenta, which, as usual, is attached to the fundus of the uterus. The ramifications of the umbilical vessels are seen to be distributed on that free surface of the fœtal placenta which is covered by the amnion. At *e* is the amnion, at *d* the chorion, and at *h* the os uteri. In the latter we remark the numerous

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glandulæ Nabothi, which are closed sacs probably connected with the secretion of this part. A gelatinous plug of mucus, *g*, often closes the orifice of the os uteri till nearly the end of pregnancy.

The small size of the uterus in this wood-cut is due to the considerable contraction which it undergoes after the evacuation of the liquor amnii, and the removal of the child. Its bulk is not even increased by advancing putrefaction.

2238. The primitive streak[47]) or groove is the first indication of the future embryo. It consists of a very small longitudinal groove in the middle of the upper surface of the serous lamina (§ 2223). It soon after enlarges, while its two margins are raised to form the *laminæ dorsales*. These grow over towards each other, meet in a longitudinal suture, and thus enclose a cavity, the primitive tube. Anteriorly this tube dilates into several vesicles, which lie behind each other, and in which is deposited the cerebral substance. The spinal cord is laid down in its remaining cylindrical portion. The several parts of the brain of the human embryo gradually pass through numerous transitional forms, which correspond with their permanent conditions in various of the lower animals.

2239. A dense cord, the *chorda dorsalis*, is early deposited beneath almost the whole length of this primitive tube. At the same time, square spots are observed on either side, symmetrically arranged in pairs. Each two corresponding squares subsequently grow towards each other, to construct the body of a vertebra (*a b*, Fig. 230, p. 393). In doing this, they include between them a corresponding segment of the chorda dorsalis, and gradually altogether displace it. In mammalia and birds, the remaining portions of this structure subsequently disappear.

2240. The vertebral arches commence as dense curved pairs of streaks; each of which unites, on the one hand, with the body of the vertebræ, and on the other, with its opposite fellow. The various processes of the vertebræ are only added subsequently.

2241. The first rudiment of the skull is formed by a membranous capsule, which gradually merges into a special cartilaginous covering, called the primordial skull. Some portions of the latter are ossified immediately afterwards; while others disappear after new pieces of bone have been apposed to them.

2242. The blastema adjoining the inferior surface of the skull produces a series of pairs of processes, which finally give rise to the chief structures of the face and neck. Those which lie between the future mouth and the chest are called the branchial or visceral processes; and the fissures which remain between them, the branchial fissures. Their form and relations to the vascular trunks which supply them somewhat resemble the type met with in the gills or branchial respiratory organs of the fish (§ 725).

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2243. The margins of the central portion of the serous lamina are gradually involuted, so as to form the walls of the thoracic and abdominal cavities. But as they only subsequently meet in the inferior median line of the embryo (which we are supposing to be horizontal), there remains at first a long fissure, through which are protruded the heart, a large portion of the intestinal canal, and the allantois (§ 2233). This aperture afterwards closes in the region of the thorax, and the posterior part of the abdomen; and finally disappears, leaving no relic save the navel. The ribs commence as dense striæ, which first become cartilaginous, and are then ossified. The several pieces of the sternum are developed by a similar process.

2244. The extremities are at first altogether absent. They subsequently sprout in the form of small stumps. Each of these is first divided into an internal segment which pertains to the trunk, and corresponds to the thigh or upper arm, and a free terminal plate which is developed into the hand or foot. This stage of development may be partially recognized in the embryo represented by Fig. 394. The forearm and leg are only formed subsequently. The fingers and toes are at first united by a kind of web, so as to resemble fins. This membrane begins to disappear from without inwards.

2245. The eye at first forms a hollow vesicle, which is connected with the brain by a tubular handle, the future optic nerve. The retina is produced from a deposit which resembles that of the cerebral substance in the vesicles of the brain (§ 2238). The crystalline lens, the vitreous humour, and the iris, are only developed subsequently. A special vascular tunic, the capsulo-pupillary sac, surrounds the lens of the early embryo. Its anterior segment then forms the pupillary membrane, a vascular coat which is stretched immediately in front of the pupillary aperture (c, Fig. 150, p. 273). By the gradual loss of its blood-vessels, this is converted into a simple transparent membrane, which disappears a few days after birth.

2246. The labyrinth of the ear also begins as a hollow vesicle, having a handle which is continuous with the brain. The vestibule, the cochlea, and the semicircular canals are then developed, at what is comparatively a very early date. The formation of the auditory ossicles is intimately connected with the development of the most anterior visceral arches. At this period the long process of the malleus extends on the first maxillary process, or the future lower jaw, as far as to the median line; in the mammalia, however, it afterwards gradually disappears, so as to leave scarcely a trace. The tympanic cavity is chiefly developed from the gap situate at the first visceral arch. The external ear is produced last of all.

2247. The organs of smell are also first indicated by vesicles which are connected with the brain. The nose is developed afterwards, during the

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evolution of the face. The palate, which is subsequently laid down, ends by separating the cavities of the nose and mouth. The tongue grows out of the first maxillary arch. The external integument is only separated into corium and epidermis towards the end of the second month, or the beginning of the third. It afterwards acquires its nails, together with its various glands and hairs. In the advanced embryo, almost all the surface of the body is covered by a very fine down. The copious desquamation and fatty secretion of the skin result in a caseous substance, which covers many portions of the fœtal body, and is capable of protecting it like an ointment (§ 130) from the injurious action of the liquor amnii.

2248. Those primary changes by which many of the embryonal organs commence are effected without the aid of the vascular system. The heart subsequently begins as a tube which, anteriorly, is continuous with centrifugal vessels or arteries; posteriorly, with centripetal tubes or veins. It afterwards undergoes a peculiar involution, divides into segments, produces the auricular appendages, and finally presents two auricles and a single ventricle. The latter gradually acquires a septum, which is at first an incomplete, and finally a perfect one. These embryonal vessels gradually undergo numerous changes; which are due, not only to the formation or metamorphosis of those organs of the body that are rich in vessels, but also to a variety of causes which belong to the vascular system itself.

2249. The contrast of a systemic and a depurative circulation obtains at a very early date. A great part of the surface of the yolk is at first covered by a vascular distribution, the *area vasculosa*, in which the blood of the embryo is changed by a process the details of which are at present unknown. This vitelline circulation begins soon after the heart of the embryo has commenced to beat. In the mammalia it subsequently disappears, to make way for the placental circulation. The blood then runs through the umbilical arteries into the fœtal placenta, where it undergoes a diffusion with the blood of the maternal placenta, returning to the fœtus through the umbilical vein (§ 2234). The renovation thus produced corresponds, not only to the respiration of the more developed being, but also to the most pressing requirements of its nutrition.

2250. The connection between the state of development of the heart and that of the great vessels, produces a peculiar movement of the blood, which has been designated the fœtal circulation or the circulation of Sabatier. It is most distinct shortly after the middle of pregnancy. The blood of the right ventricle then passes chiefly into the lower half of the body and the placenta. While that which returns from this organ goes chiefly to the left heart (§ 572), in order to flow thence to the head and neck, from which it finally returns to gain the right auricle and ventricle. So that there is a partial contrast between the circulations of the upper

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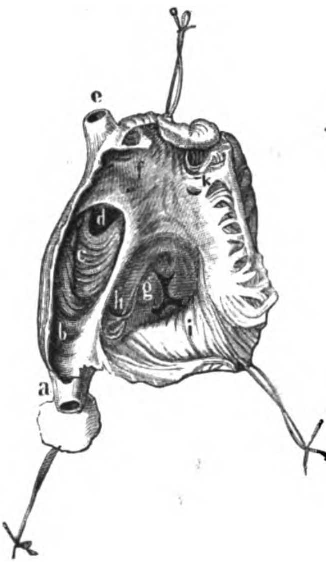
and lower halves of the body. After birth it is replaced by the systemic and pulmonic circulations.

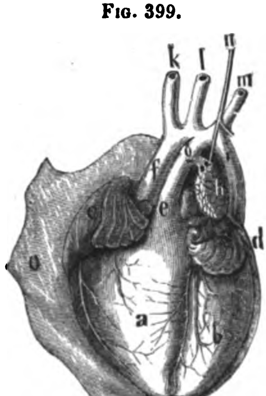
2251. The placental circulation ceases soon after birth, being replaced by the pulmonic on the respiration of air. But in the normal course of development, the preparations necessary for this change are made some months before the end of pregnancy. Hence, under favourable circumstances, a child which comes into the world seven or eight months after conception may nevertheless continue to live.

Fig. 398.



2252. We have already seen (§ 731) that the circulation of the new-born infant includes many arrangements, which date from its fœtal state, and are only gradually lost in the earlier months of its life. The foramen ovale (*d*, Fig. 398) is due to the fact, that the inferior vena cava (*a*) originally opens into the left auricle, and not into the right; being only gradually pushed over into the latter. This explains why the greater part of the blood that returns from the umbilical vein and the lower parts of the body passes into the left auricle during the fœtal circulation (§ 2250). The groove (*b*) which conducts it in this course is the relic of a special adaptation, which dwindles and disappears in proportion as the left auricle is claimed by the advancing development of the pulmonary veins. Immediately after birth, the foramen ovale is at first closed mechanically by the action of the auricle; but it finally becomes organically occluded. The superior and inferior vena cava (*e* and *a*, Fig. 398) then belong exclusively to the right auricle.

Fig. 399.

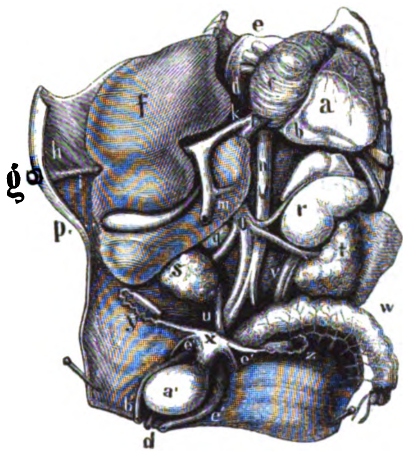


2253. The pulmonary artery (*e*, Fig. 399) and aorta (*f*) of the new-born infant are connected with each other by means of the *ductus arteriosus*, or duct of Botalli (*g*). This structure, — which is a necessary result of the development of the embryonal vessels — prevents the two divisions of the fœtal circulation (§ 2250) being completely separated from each other,

and also hinders the perfect separation of the scarlet and dark-red blood in the new-born infant whose lungs have begun to work. But in the first few weeks after birth, the ductus arteriosus is closed, by a process which somewhat resembles that seen in a deligated artery (§ 1074). It is thus converted into a ligamentous band, in which form it remains during the remainder of life.

2254. The annexed woodcut (Fig. 400), which was drawn from the same eight months' fœtus as the two preceding, may illustrate another special relic of the fœtal circulation. After a certain period of embry-

Fig. 400.



onal life, the umbilical vein (*g i*, Fig. 400) which returns the renovated blood from the fœtal placenta, sends branches to the liver (*f*). Besides this, it unites with the portal vein (*m*), which also ramifies in this gland. And it has also a certain communication with the inferior vena cava (*l*); by means of a vessel—the venous duct of Arantius (*k*)—which passes between the two. Hence part of the purified blood which is returning from the fœtal placenta can avoid the liver, and flow (through *k* and *l*) immediately into the auricle (*c*).

2255. The umbilical cord of the infant is usually tied and cut through in some part of its course. The brute mammals gnaw it asunder as soon as their young have breathed. After some time, that portion which remains attached to the belly dries up, and falls spontaneously from the navel. Those portions of the umbilical arteries (*b c*, Fig. 400) which first run along the bladder (*a'*), and then ascend on the abdominal walls to the umbilicus, become converted into ligamentous tissue. The duct of Arantius and a large part of the umbilical vein (*i*, Fig. 400) also experience the same fate.

2256. The development of the intestinal canal commences by the centre of the mucous lamina being raised and folded inwards. In this

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way it produces an intestinal groove, which is open towards the yolk. This groove is soon afterwards shut off anteriorly and posteriorly, so that there only remains a median gap, the intestinal navel (*e*, Fig. 396, p. 652). We have seen (§ 2232) that the circumference of the mucous lamina furnishes a covering for the umbilical vesicle (*c c*). The portion (*e*) which intervenes between this and the intestinal navel is drawn out into a cylindrical duct, the pedicle or stalk of the umbilical vesicle.

2257. The rudiment of the alimentary canal, which forms a tube open at the navel, is at first closed at its anterior and posterior extremities. Its anterior end corresponds to what is afterwards the cardia of the stomach (*q*, Fig. 9, p. 34), and the posterior to the junction of the middle and lower portions of the rectum. The termination of the latter, as well as the œsophagus and mouth, are only developed subsequently.

2258. The stomach originates as a protrusion from the anterior part of the rudimentary intestine; and is at first directed longitudinally, or parallel with the vertebral column. It afterwards assumes the horizontal position which it presents in the adult. The remainder of the intestinal tube gradually undergoes a considerable elongation, and at the same time forms convolutions, which continually increase in number. The spiral coil which is first seen protrudes at that time from the navel (§ 2243). It is afterwards retracted into the abdominal cavity. The form of the large intestine, and the separation of its various segments (§ 400), are comparatively late to appear. The peculiar course of the peritoneum and great and small omentum can only be satisfactorily explained by the history of their development.

2259. The blastema of the glands is at first a transparent gelatinous substance. It then exhibits simple branchings; which end by blind extremities in what are subsequently the ramified glands (§ 857). Their number gradually increases, until they finally involve the greater part of the blastema, the margins of which gradually become lobulated. In this way they form the permanent gland-ducts. The terminal enlargements and the main ducts are at first separate cavities, which only unite subsequently. The ramifications of the bronchi originate in precisely the same manner. The liver is of comparatively large size during the greater part of fœtal life. The thyroid gland and the thymus also arise from a blastema, which developes tubes that remain closed on all sides.

2260. The development of the urinary and sexual apparatus is preceded by that of two comparatively large tubular glands—the Wolffian bodies or primordial kidneys. Like the permanent kidneys (§ 935, [*a*, Fig. 153, p. 284]), they possess Malpighian coils of vessels; and have a special efferent duct, which conveys their secretions towards the common orifice of the allantois and rectum. They disappear after the

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permanent kidneys have reached a certain degree of development. Some of their constituents utterly perish; while others — according to many observers — assist to form various structures of the sexual organs.

2261. The true kidneys and ureters originate on the wall of the belly behind the primordial kidneys. Their surface is at first smooth; but subsequently, when the course of the urinary tubules (*e f*, Fig. 152, p. 283 [§ 934]) renders the difference of cortical and medullary substance more distinct, it is separated into roundish lobules (*s t*, Fig. 400, p. 659). After birth they recover their smooth surface, which is thenceforth permanent. The bladder is produced from the lowest part of the allantois. The upper part left between the apex of the bladder and the navel is converted into the urachus or urinary cord (§ 942 [*d'*, Fig. 400]).

2262. The male and female sexual organs are preceded by a series of similar deposits. The true divergent course of either can only be recognized in the course of their subsequent development. Hence there is a period at which the sex of the embryo is sometimes better deduced from the general form of its body than from a mere glance at its genitals.

2263. The testicles and ovaries are at first small reniform masses, which lie internal to the Wolffian bodies (§ 2260) in a special fold of peritoneum. The testicles soon offer distinct seminal tubes. The substance of the fœtal ovary already contains rudiments of follicles and ova (§ 2152). The testicles leave the abdominal cavity before birth. But the ovaries only descend more deeply into the pelvis.

2264. The young mammalian embryo exhibits on each side two filaments; the efferent duct of the primordial kidney (§ 2260), and the Muellerian cord. According to Kobelt, in the male the former is converted into the vas deferens, while the latter almost disappears. But in the female the latter is developed into the Fallopian tube. And while in the human species, the efferent duct of the primordial kidney entirely disappears, in some animals it is partially retained as the Gartnerian canal.

2265. The two Fallopian tubes unite to form a middle portion or uterus, which has at first two *cornua*, even in the human subject. The simple pear-shaped uterus of woman (*w*, Fig. 9, p. 34, and *a b*, Fig. 386, p. 630) is only developed subsequently. But in the male embryo of the mammal, we find a median portion that resembles the uterus. Its bulk at first equals that of the uterus of a female embryo of the same age. But it afterwards dwindles, without however absolutely disappearing. In the adult male, the *vesicula prostatica* (*p*, Fig. 383, p. 626), which is covered by the prostate (*y*, Fig. 382, and *r s*, Fig. 383), and lies between the ejaculatory ducts (*n o*, Fig. 383), is the more or less developed relic of this embryonal uterus.

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2266. At about the middle of fœtal life the external organs of the two sexes closely resemble each other. Hence a male fœtus is often mistaken for a female, and *vice versâ*. Similar mistakes may even occur after birth. And what are called human hermaphrodites do not possess both testicles and ovaries, like the true androgynous animals (§ 2085); but are rather due to a part of the organs of generation experiencing an arrest of development at that stage when their outward form most resembles that of the female structures. In this way a boy has more than once been clothed and educated as a girl, until at the age of puberty, the true state of things has been betrayed by the beard, the voice, and especially by the sexual inclination.

2267. The bladder or lowest part of the allantois, together with the ducts just mentioned (§ 2264) and the rectum, all originally open into a common cloacal cavity. From this the rectum is first shut off. The terminal orifice of the remaining tube, or the uro-genital canal, acquires tumid lips, which subsequently form the scrotum of the male, or the external labia of the female. From the fissure left between these lips projects a pedicle, which finally enlarges at its extremity, and is converted into the penis or clitoris. In the male, it enlarges and remains free, while the cavity bounded by the lips below is lost by their growing together to form the scrotum. In both sexes the urethra is folded off from the genital canal. It at first opens at the base of the penis, and is only subsequently prolonged through its interior.

2268. In both sexes a special hollow cylinder, which is closed at both extremities, passes from the neighbourhood of the testicle or ovary to the inguinal canal. It is called the conducting ligament of Hunter. In the female it retains this position, becomes ligamentous, and is thus converted into the round ligament of the uterus (*e'*, Fig. 400, p. 659). While in the male, it forms the *gubernaculum testis*, which precedes the testicle in its descent from the cavity of the abdomen into that of the scrotum (§ 2263). The descent of the testicle explains the origin of the sac of its *tunica vaginalis* (*u*, Fig. 382, p. 626, and § 850), and the great liability to inguinal herniæ, especially during the earlier years of life.

2269. Most of the tissues of the organized being are preceded by nuclei; either alone, or in connection with cells. This proposition is generally designated the cell-theory of Schwann. The phenomena of nutrition have already taught us that in many parts of the animal, the cell is retained permanently, while in others it is replaced by cell-fibres, homogeneous membranes, special fibres, osseous substance, and the like. The minute details of these changes belong to general anatomy, and would require a special study of the history of development[49]). But we have already seen (§§ 1225 and 2061) that the embryonal structures are capable of contraction and other energetic acts before attaining their subsequent and permanent form.

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2270. Since the course of embryonal development is accompanied by great alterations of form, abnormal circumstances may either prevent the production of an organ which ought to be present, or may give it a form that corresponds to an earlier stage of development. Such deviations are called arrests of development. Examples of them may be found in the want of a single limb, all four extremities, the fore-arm, or the leg; as well as in the union of the fingers or toes by a kind of web (§ 2244); and in hare-lip, cleft-palate, and so forth. But other deviations—such as the cerebral dropsy which produces congenital cretinism (§ 2057),—are due to the incursion of a definite disease, which is favoured by the early stages of development. Hence arrests of development are often mixed with acquired diseases. All the irregularities met with in the simple monstrous births may be referred to these two chief groups.

2271. Sometimes only a limited portion of the body is doubled; such as the last phalanx of the thumb. In other cases, the double character extends to a large number of organs, sometimes producing a nearly perfect and symmetrical double body—or a double monster, as it is called. Triple monsters are extremely rare. These facts suffice to indicate that the double monster is rarely produced from two ova, or from the subsequent fusion of two embryos. On the contrary, it would rather seem that, under these circumstances, the germ or early organic rudiment behaves like the corporeal mass of one of the lower invertebrata in the act of repairing an injury (§ 1062). Be that as it may, it is certain that when some of the earlier organs are double, those on which they act, and which are subsequently developed, are double also. The truth of this proposition has been decided by a careful investigation of the development of a double monster in the pike: and may be easily explained from the statements in § 8.

2272. *Birth.*—It is generally laid down as a rule, that the child comes into the world at the end of the tenth lunar month, or 280 days after conception. But since various external causes or internal abnormal conditions may induce birth at any period during pregnancy, an apparently mature child may be born before the lapse of 280 days. On the other hand, we are justified in presuming that the fœtus is sometimes retained in the uterus beyond this period. And apart from this consideration, the whole calculation has no starting-point which is accurate to a day. If we take the cessation of the last menstruation, we reckon one or more days too many. And even the date of coition allows of a somewhat similar error, since it is not the entry of the semen, but its contact with the ovum (§ 2181), which is really decisive.

2273. It has been very properly conjectured that the periodical recurrence of the sexual excitement must determine, not merely the menstruation of the unimpregnated female, but the occurrence of natural parturition in the pregnant one. The pains are therefore supposed to

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appear at what would have been the tenth repetition of the menses; or a few days earlier, if we assume that the unimpregnated organs of generation require some time to prepare for their tenth menstruation. But here also the difficulties above mentioned prevent all accurate calculation.

2274. In the latter months of pregnancy the child generally lies with its head downwards, as represented in Fig. 401. The periodic and painful uterine contractions which accompany the act of parturition, exert a pressure on all sides of the ovum, and on the structures which it contains. They thus extend the region of the os uteri (above *c*, Fig. 401). This orifice now opens, and gradually dilates. That portion of the ovum which lies before the head of the fœtus is protruded into the vagina (*c*, Fig. 401) at the instant of each active pain. As the head is more wedged in, this gradually becomes more and more tense. It finally bursts, and thus permits the exit of that small quantity of the liquor amnii which was contained in it, and was shut off from the remainder

FIG. 401.

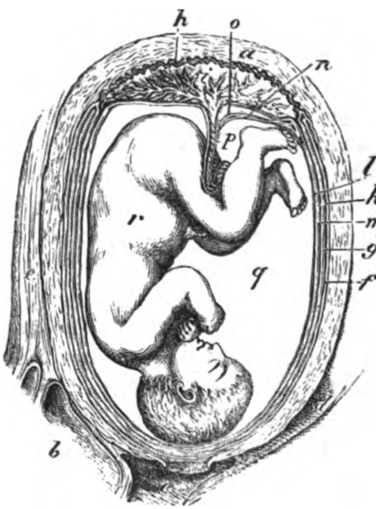
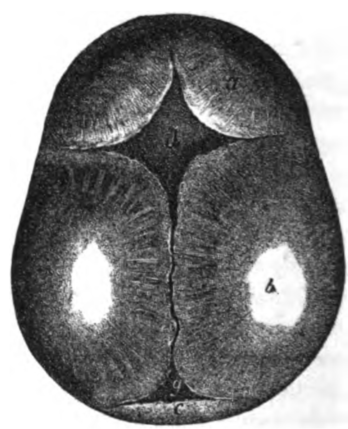


FIG. 402.



by the head. The child's head is then exposed. The pains, which continually increase in violence and frequency, gradually propel it through the os uteri and the vagina. During the most urgent moments a powerful abdominal pressure (§ 393) is added to these uterine contractions. The remainder of the body shortly follows. But both it and the head undergo a suitable rotation in the different stages of parturition. The fontanelles (*d* and *g*, Fig. 402),—together with the still cartilaginous pieces of the frontal (*a*), parietal (*b*), and occipital (*c*) bones, and the other parts of the head,—permit the bones of the skull to approach or

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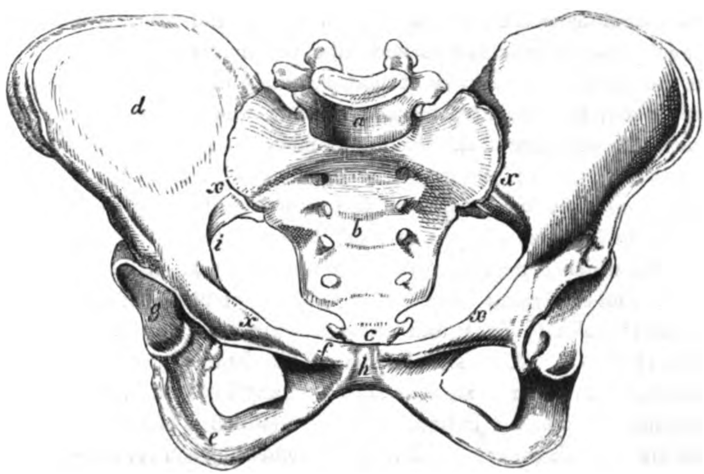
even overlap each other; and thus facilitate the transit of this, the bulkiest portion of the child.

2275. The violent pain which accompanies parturition is due partly to the contractions of the uterus, partly to the narrowness of the passage through which the child is expelled. The human female has a more painful parturition than the brute mammal, since the peculiar construction of her pelvis (Fig. 403) leaves comparatively less space (*x i b c*) for the transit of the fœtus. But this unfavourable arrangement is a simple consequence of upright progression (§ 1324).

FIG. 403.



2276. The mucus poured out from the vagina often contains a few streaks of blood before the head has yet left the os uteri. In its subsequent passage, the head often tears the lips of this part, and thus causes the ultimate production of cicatrices which betray a previous parturition. This process is frequently accompanied by a trifling, but instantaneous, hæmorrhage. The expulsion of the child is immediately followed by that of the remainder of the liquor amnii (*q*, Fig. 401). At this moment a vigorous hæmorrhage generally occurs, since the uterus (*a*, Fig. 397, p. 654) has usually contracted enough to separate a portion of the fœtal from the maternal placenta (§ 2234). One or more trifling pains complete its separation, and then expel the after-birth.

2277. The opposite woodcut (Fig. 401) will show what parts the after-birth contains. The bulk of it is formed by the fœtal placenta (*i*),—the uterine surface of which gives off the navel-string (*p*), and is occupied by blood and some fragments of the latest deciduous membrane (*see h*, § 2226). The remainder consists of the membranes of the ovum, which are torn at the place where the child previously passed through them;—

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these are the chorion (k), the amnion (l), and the thin layer of albumen which lies between the two. The decidua reflexa (g) is not very distinct during the latter months of pregnancy. Some fragments of the decidua vera (f) are usually expelled with the after-birth. A relic of the umbilical vesicle (o) is but rarely found (§ 2232).

2278. During the puerperal state, the emptied uterus undergoes a continual diminution, which reduces it to its former size. A series of painful and periodic contractions, called the after-pains, at first occur. Primiparous females generally suffer less in this respect than those who have frequently borne children. The *lochia* or puerperal cleansings, are composed of a considerable quantity of dark and offensive blood, which is discharged from the genitals in a state of partial coagulation. These are finally mixed with exsudations, like the menstrual blood (§ 2164). Like the menses, the lochia at first resemble water in which flesh has been soaked, subsequently become mucous, and finally altogether disappear. Those relics of the deciduous membrane which still remain in the uterus (§ 2277) are gradually expelled with the lochia. In this way that mucous membrane of the uterus which was loosened and changed during pregnancy is cast off, to be succeeded by a new lining membrane which is developed from the deeper layers left behind.

2279. *Post-embryonal Development.*—Many months before birth, the skeleton, muscles (§ 747), and corresponding segments of the nervous system (§ 2034), which sustain the mechanism of respiration, are so far developed as to be capable of acting at any instant. If the ovum of a mammal be extracted entire, the embryo (which is still enclosed in the liquor amnii) makes deep respiratory movements when its navel-string is compressed, its placental circulation impeded, or when it is threatened with suffocation from any cause whatever. And when the mature human fœtus exchanges the fluid medium hitherto surrounding it for the elastic atmosphere, the play of respiration soon begins; and, from this time forth, cannot be interrupted without imminent danger to life for even short intervals of time. On emerging from the vagina, the child generally betrays its first respiration by a cry. And as soon as the pulmonic circulation (§ 570) has been properly set in action by a series of respiratory movements, the placental circulation (§ 2249) ceases spontaneously. The pulse of the umbilical arteries at once disappears. The navel-string may then be tied and cut through externally to the ligature, to allow of the child being removed from the after-birth.

2280. *Milk* is the most natural food of the infant. The breasts prepare for their subsequent secretion even from the middle of pregnancy. But so long as the maternal placenta retains its action, their enlargement is but limited. About the second or third day of the puerperal state, they swell considerably. The substances now no longer

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directly necessary to the fœtus, move, as it were, towards the breasts, to take the form of food for the child. During the continuance of suckling, the menses generally remain absent. Still they sometimes return, without in any way affecting the secretion of the milk.

2281. The fluid which is prepared in the first days of the puerperal state, or before there is much swelling of the breasts, is called the *colostrum* or "beestings". The subsequent secretion is called milk, in the narrower sense of the word. The different microscopic constituents of the two fluids are shown in Tab. V., Figs. 79, 80. Here Fig. 79 represents the elements of the colostrum of a woman the day after parturition; and Fig. 80 those of the milk of a person who had been confined ten weeks previously. Both contain milk corpuscles;—*i. e.* small globules of oil or butter, surrounded by a protective albuminous layer called the *haptogenous* membrane. But the fluid portion of the milk contains casein (§ 311) in a state of solution (§ 346). The milk corpuscles of the colostrum (*a b c*, Fig. 79) differ much more remarkably in size than those (*a*, Fig. 80) of the subsequent milk, in which the larger forms of the beestings can no longer be recognized. The colostrum also contains a large number of peculiar structures (*d*, Fig. 79) called colostrum corpuscles; which are either absent from the subsequent milk, or are at any rate much less frequently met with (*b*, Fig. 80).

2282. According to Will,[49]) the milk-corpuscles are deposited in the form of oil drops, which are contained within the gland-cells (§ 863) that clothe the ducts of the mammary gland, and are subsequently set free by the solution of their parent cells. While the colostrum-corpuscles are special parent cells, which are expelled as such. Epithelial cells (*e*, Fig. 79) from the nipple are also now and then admixed.

2283. We have already seen (§ 346) that the milk is an admirable mixture of the most important constituents of the food. According to F. Simon, human milk contains 82·5 to 91·5 per cent. of water, 2· to 4·5 of casein, 3·9 to 7· of sugar, 1·4 to 5·4 of butter, and ·17 to ·32 of fixed salts. The colostrum yields a larger quantity of solid residuum and fixed compounds. It acts upon the new-born infant as a purge. Hence the infant in its first days of life evacuates a green fœcal mass or *meconium;* which consists of shed (and partly dissolved) epithelium, a mucous basis, and relics of bile. The presence of the latter constituent explains why the meconium often gradually deposits microscopic crystals of cholestearine in the open air (§ 308, and Fig. 164, p. 301).

2284. The novelty of the atmospheric medium around it probably contributes to that vigorous desquamation which the skin of the new-born infant undergoes. In many places the hairs fall off, and are replaced by new ones which (according to Koelliker) lie already prepared in their neighbourhood. Hence we have here a process resembling that which obtains in the teeth (§ 2286).

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2285. The first teething[50]) forms, to some extent, the natural limit of the age of suckling. Preparations for the development of the teeth may be observed in the third month of embryonal life. Their crowns are gradually developed during the remainder of pregnancy. Shortly before or after birth their roots also grow rapidly; gradually pushing the crowns forward as they do so. Those of the incisor teeth are generally cut in the second half of the first year of life. But, in rare instances, the infant comes into the world with some of its teeth already protruding. The twenty milk-teeth—viz. the eight incisors, the four canines, the four first, and the four second molars—are rarely all cut before the end of the second year, or the beginning of the third.

2286. The change of teeth which occurs between the seventh and thirteenth year consists essentially in the replacement of the milk-teeth by others. The latter, which were developed long before, but hitherto occupied the bottoms of the maxillary cells, now grow up, displace the milk teeth, and finally cause them to fall out. Since the hindmost molars have no corresponding milk teeth, those which arise in this situation are permanent: in other words, they are destined to serve for the whole remaining life, and should they fall out, are not replaced by others. The rudiments of all the permanent teeth may be seen in the early part of fœtal life. And just as perfect teeth are sometimes found in tumours, so, in rare instances, old people who have lost their teeth for years develope new ones.

2287. The period of puberty in the male is chiefly characterized by the appearance of semen in the testicles, and by the capability of emission and fertile intercourse; and in the female, by the appearance of menstruation, and the capacity of becoming pregnant. The breaking of the voice (§ 1422) often betrays this change—especially in the male. The sexual maturity of the boy is almost always attained without any disturbance; while, in the girl, its development frequently gives rise to various morbid phenomena. But in both, it causes the appearance of a series of important peculiarities. In the male, the powerful manly form, the beard, and the desire after women, attend the age of puberty. While in the female, the graceful roundness of outline, the fulness of the hips—which is connected with the development of the pelvis (§ 2275)—and the inclination towards men, appear with the first occurrence of the menses. Hence castrated or impotent men have a body which is less powerful and more inclined to the deposition of fat, an imperfect growth of beard, a smaller larynx, and a feminine pelvis; while women whose menses flow sparingly have stronger bones and muscles, deeper voices, and more masculine bodies and minds.

2288. At the period called the turn of life (§ 2157) the female organism undergoes important changes. A rapid and striking alteration of the features then testifies that the epoch of fertilization is past. Persons

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who were scrofulous in childhood and only acquired health on the appearance of the menses, and others who have remained childless or germinated some suppressed disease then become very liable to cancer of the breast or uterus.

2289. In old age we with difficulty preserve what the earlier years of our life have constructed. The bulk of the body is gradually diminished. Most of the functions lose their customary vigour. Large quantities of inorganic substances are deposited in many places. The valves of the heart, and the walls of the arteries, become extensively ossified (§ 1033). The bones become brittle, and contain more spongy or cancellated tissue (§ 1039). Both of these circumstances favour the occurrence of fractures. The weakened circulation frequently causes the death by mortification of parts which, like the toes, are remote from the heart. And since all those masses of fat which are not indispensable for mechanical purposes gradually disappear, numerous wrinkles become visible in the face and many other parts of the body. The muscles diminish in bulk. Their weakness leads to fatigue on slight exertion; as well as to uncertainty of gait, and permanent curvature of the vertebral column (§ 1325) and neck. Asthma, bronchitis, dropsy and other serious maladies, are frequently developed as a consequence of disturbed nutrition. The senses and the mind often lose their previous accuracy. The flame of life goes slowly out, or is sometimes suddenly extinguished in a way unexpected even by the physician. The maximum of human life hitherto known is 170 years.

2290. The changes which occur in the course of post-embryonal development are best illustrated by the average weights of the body[51]) at different ages. The new-born infant weighs from 6·62 to 6·84 pounds. The weight subsequently increases up to the 40th year in the male, and the 50th in the female. Both then exhibit a weight about 19 or 20 times as great as that of the new-born infant.

2291. The sucking child doubles its weight during the first year of life. The increase of the second year is but 1-5th. Between the third and twelfth years this sinks to an annual average of about 1-10th. During the development of puberty (§ 2287) it rises to 1-8th or 1-7th. From the 16th or 17th years the corporeal mass experiences less change. It still increases, however, in the following ten years. This increase of weight is finally so small, that the man gains on an average only 3-10000ths between 30 and 40, and the woman only 17-1000ths between 40 and 50. From this time the absolute weights of the body continually decrease. This loss in the man amounts to 3-1000ths between 50 and 60, 1-50th between 60 and 70, and 1-25th between 70 and 80. Finally, the old man of 90 is only 18, and the old woman of the same age scarcely 17, times the weight of the average new-born infant.

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INDEX.

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